M.K. POLTEV

Occupational Health and Safety in Manufacturing Industries

MIR PUBLISHERS MOSCOW

M.K. Poltev graduated from Moscow Institute of Civil Engineering in 1952. He received his Cadidate of Science degree in 1959.
Professor Poltev heads the Instruction and Methodology Department at the USSR Ministry of Higher, Secondary and Specialized Education and reads lectures at the All Union Polytechnical Intitute for extra-mural studies.
He has to his credit about 65 works on occupational safety and health problems of whic the book Occupational Health and Safety in Manufacturing Industries has won the Silver Medal of the Exhibition of USSR Economic Achievement in 1982.

The book is written specifically as a textbook for courses in accident prevention in manufacturing industries. This text gives the background to the legal measures on labout prorection, industrial and hygenic requirements, accident and fire prevention and shows application of such requirements to the practical development and operation problems.

The author's methodological approach is designed to examine first the possible factors that are harmful to human life and health and are likely to arise at the stage of development operation and maintenance of new equipment and manufacturing processes. It further describes modern methods, provisions devices that are instituted to eliminate the hazardous factors or reduce the harmful social consequences they cause. Factors of safety are covered in detail with sections on the individual protection from the deleterious influence of gas, dust, noise, vibration, radiation and electric current. Although written particularly for students and young graduates as a helpful supplement to the engineering courses, the book should be essential reading for practising engineers and designers.

M.K.POLTEV

OCCUPATIONAL HEALTH AND SAFETY IN MANUFACTURING INDUSTRIES

OCCUPATIONAL HEALTH AND SAFETY IN MANUFACTURING INDUSTRIES

М.К.ПОЛТЕВ

ОХРАНА ТРУДА В МАШИНОСТРОЕНИИ

МОСКВА·ВЫСШАЯ ШКОЛА·

M.K.POLTEV

OCCUPATIONAL HEALTH AND SAFETY IN MANUFACTURING INDUSTRIES

Translated from the Russian
by V. KOLYKHMATOV

MIR PUBLISHERS MOSCOW

First published 1985
Revised from the 1980 Russian edition

На английском языке

CONTENTS

PREFACE

Industrial machinery is largely responsible for the need of safety precautions and has always been a matter of major concern in the field of accident prevention. In the early years of the Industrial Revolution it was machinery that caused spectacular accidents in factories which arouse public opinion and led to safety legislation. Some of the earliest measures to enforce labor laws and safety inspection were designed to reduce the hazards inherent in machinery. Machinery is still important from the accident-prevention standpoint.

Many changes occurred over the years in the nature of industrial accidents with the introduction of steam-powered industrial machinery; later with electricity that gave rise to yet other types of accidents; with the replacement of coal by gas and oil; with the internal-combustion engine that also has its dangers.

The manufacturing industry today makes rapid advance due to fast progress in science and technology, development of new types of machine-tools, intensive use of industrial equipment and machinery, improved methods, practices and processes, and better maintenance, repair and servicing of industrial equipment. The continuous mechanization and an ever-increasing variety of chemicals, that are now widely in use, add up yet more problems of labor protection in the industry. The recent hazards that have lately arrived are those from ionizing radiation and atomic power.

Technological changes, however, do not always result in increase of industrial accidents. In the recent years it has come to be realized that technological advance cannot be held entirely responsible for accidents. It is therefore not suprizing that increasing attention is paid to accident risks inherent in human behavior in the factory or other workplaces.

This manual is an attempt to give a general idea of what labor protection involves in the way of legal provisions and practical measures to protect health and prevent accidents in the industry. Its major aim is to provide a better understanding of the complexities in the field of labor protection, and of present-day social and industrial life.

The book examines methodically the subject of occupational health considering in details various industrial safety and health hazards that may arise in the various sectors of the manufacturing industry from design, construction, use and maintenance of machinery and other industrial equipment. It explains why safety is important, by what methods it is promoted, what authorities, institutions are responsible for promoting it. Although it does not pretend to cover every occupational field, it is also a technical manual. It offers methods, devices that help avoid industrial hazards or reduce the harmful consequences they may cause. The manual suggests practical solutions for the application of the various preventive measures and standards of industrial safety and hygiene provided for by way of law, regulations and national and sectorial safety standards. The book contains useful material for the students of mechanical engineering majoring in accident prevention and industrial hygiene. It is, in fact, addressed almost exclusively to workers in manufacturing industries, and will give little specific guidance to the miner or the farm worker.

INTRODUCTION

Industrial accidents began to occur in large numbers ever since the first industries were set up in Russia, and increased as the revolution in industrial techniques began to make possible large-scale mechanized production with the factory as the production unit. Some of the conditions to which industrial growth gave rise were so atrocious as to demand for reforms. The movement for reforms was led by people who felt that they had moral responsibility for the welfare of their fellow-workers. The aim of the reformers was to persuade, shame or force governments into protecting the factory workers who often lived and worked under conditions which today would be considered shocking, from danger of mutilation and disease by taking, among other things, legal measures.

The Social-Democratic Workers' Party of Russia (the RSDRP) was the first to include in 1903 the economic demands of the industrial workers into its first political program. The program demanded the establishment of the 8-hour working day, weekly days of rest assured by law; prohibition of the overtime work—all "in the interests of protecting the working class against the physical and moral degradation, and in the interests of developing its ability to fight for its liberation".

The first achievement of the 1917 October revolution was the 8-hour working day enforced by one of the first decrees of the Soviet state issued a day or two after Soviet power was proclaimed.

The Soviet state has paid much attention to the growing importance of new technology, complexity of industry and promotion of safe working conditions in the industrial undertakings and underlined that the overall electrification of the country would greatly improve hygienic conditions in industry, relieve millions of workers from smoke and dust, and rapidly convert the atrocious, dirty workhouses into clean, well-lighted laboratories decent for humans (Fig. 1).

Labor protection, or health safety, i.e. prevention of occupational disease and reduction in the frequency of accidents in industry, has always been a matter of major concern of the Soviet state. In recent years thousands of new industrial establishments using modern machinery and equipment have been put in operation.

Many old plants and factories have been modernized or substantially altered on an essentially new technological basis where machines have replaced hand labor; many arduous processes and operations

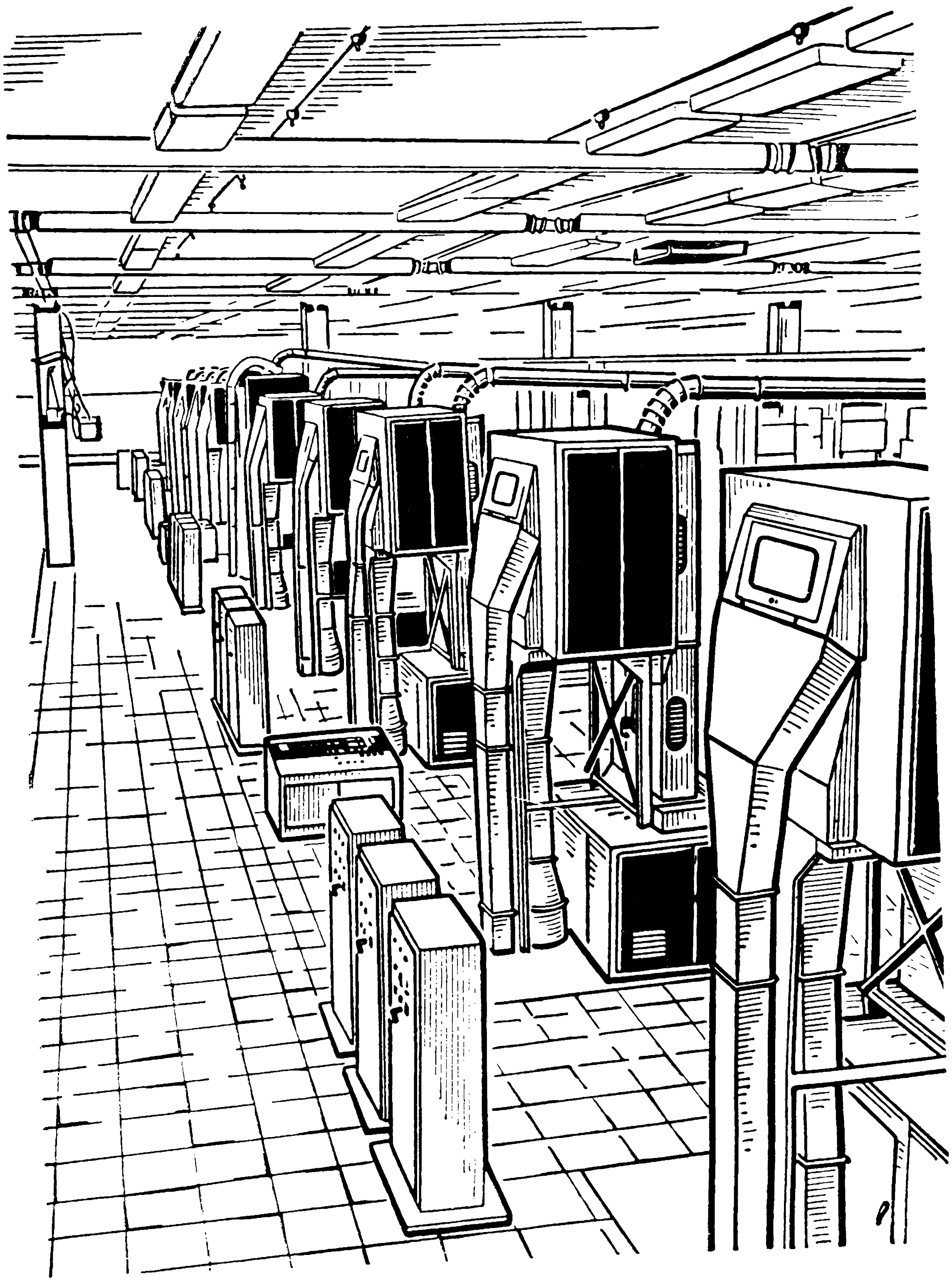

Fig. 1. Modern workshop interior

have been, fully or partly, mechanized and automated. The technological changes have greatly improved the working conditions in the manufacturing industries and thus made them safer. Huge capital spendings in the past few years on labor protection and promotion of safety and hygiene in industry have reduced markedly

the frequency of industrial accidents and occupational diseases in all sectors of the national economy.

In a number of industries, certain jobs and occupations that involve arduous and unhealthy conditions have been eliminated and many occupational diseases done away with.

Laws, regulations and recommendations will not serve any useful purpose if nothing is done to promote safety in the factory or industrial undertaking itself. The responsibilities for all the aspects of labor protection, delegation of this responsibility to the supervisory staff, the status and activities of safety committees and safety engineers lie with the management of the undertaking. The supervision of compliance with safety and industrial hygiene regulations and labor laws is done by the trade unions through their technical and legal labor inspectorates. Management and trade union should take the lead in promoting and maintaining high safety standards through practical measures intended to:

reduce frequency of industrial accidents and occupational diseases; reduce, where practicable, hand labor and jobs classed as "heavy"; provide working clothes, protective shoes and other personal protective equipment; carry out comprehensive programs to improve working conditions, safety and industrial hygiene;

promote measures to make the working conditions for women safer and more hygienic; improve their skills and provide them occupations that without causing over-exertion would give them reasonably high pay;

use the achievements of science and technology for improving the conditions of work and the protection of labor and environment; extend research programs in the field of industrial safety and hygiene; enforce and supervise compliance with safety standards and sanitation rules during design, construction or substantial alteration of industrial plants, machinery and equipment;

awaken and maintain the interest of the workers in the prevention of accidents and ensuring their cooperation in drives for safety at work and failure-free work of machines and equipment they operate.

The progress of technology renders necessary testing of industrial materials and equipment, and research in the fields such as technology, physiology and psychology. Mining is perhaps the industry for which the first safety research in Russia was done as early as 1742 by M. V. Lomonosov, who examined the various aspects of safety and hygiene of the "mining people", organization of their work and rest, reliability of the supports stabilizing rock, safety of passage by way of ladders, suitability of their working clothes, etc.

But industry has generally benefited from research in chemistry, construction materials, traction equipment, physiology and many other things among which was the theory of vorticity developed by the Russian scientist N. E. Zhukovsky. His theory has provided

the basis for the manufacture of various sorts of axial fans now widely applied in the industrial-type ventilation systems.

In one of his works the Russian physiologist I. M. Sechenov investigated the role the nervous system plays during the working process. Besides, Sechenov took precedence in developing the physiological criterium for determining the length of the working day for persons on physical work.

The industrial hygiene was extensively studied by E. E. Erisman, professor of hygiene of Moscow University. He also edited the 19-volume work on labor protection.

More than 700 research institutions in this country are presently engaged in basic and applied studies of the various problems of labor protection.

Among other objectives, research and development of new technology today persues the aim of not only making work easier, but also changing the role of man in the production process. The increasing power, speed and crowding of machinery increase the number of objects man has to control, and make work process more dangerous. Wide use has been made of remote control for operations that are dangerous and for work under environments that are harmful to human health.

Technological advance in the manufacturing industry has certainly rendered work easier and safer. Mechanized and automated processes have reduced and, in certain sectors, eliminated heavy physical and hand labor. Factory work now needs less physical efforts, becomes more intellectual and requires special training. It is not surprising that an ever-increasing attention is now paid to the human behavior in workplaces as the psychological overload of the operator during working hours has greatly intensified. Under these conditions such new disciplines as ergonomics, sometimes known as human engineering, engineering psychology and industrial aesthetics are of special importance. These disciplines directly related to industrial hygiene and accident prevention are largely intended to promote safety and health requirements in the industry, render factory work easier, conditions comfortable, and develop "safety-mindedness" in the factory personnel.

CHAPTER 1

Legal and Organizational Aspects of Labor Protection

Labor protection can be defined as a system of legal acts and relevant socioeconomic, technological and organizational measures ensuring safety and health, accident prevention and industrial hygiene, and fitness to work.

1.1. LEGAL PROVISIONS

The basic statutes on labor protection are contained in the Fundamental Law (Constitution) of the USSR, namely the Basic Principles of Labor Law of the USSR and Union republics.

It seems to be quite appropriate for present purposes to cite some articles from the Constitution concerning labor and health protection.

Thus, Article 21 of the Constitution of the USSR says that the state concerns itself with improving working conditions, safety and labor protection and scientific organization of labor, and with reducing and ultimately eliminating all arduous physical labor through comprehensive mechanization and automation of production processes in all branches of the economy.

Article 40 defines the right of the citizens of the USSR to work, that is, to guaranteed employment and pay in accordance with the quantity and quality of their work, and not below the state-established minimum.

This right is ensured by the socialist economic system, steady growth of the production forces, free vocational and professional training, improvement of skills, training in new trades or professions and development of the system of vocational guidance and job placement.

Article 41 affirms that citizens of the USSR have the right to rest and leisure.

This right is ensured by the establishment of a working week not exceeding 41 hours for workers and other employees, a shorter

working day in a number of trades and industries, and shorter hours for night work; by the provision of paid annual holidays, weekly days of rest, extension of the network of cultural, educational and health-building institutions.

Article 42 says that the citizens of the USSR have the right to health protection.

This right is ensured by free, qualified medical care provided by state health institutions; by extension of the network of therapeutic and health-building institutions; by the development and improvement of safety and hygiene in industry; by the broad prophylactic measures; by improving the environment; and by the researches directed to preventing and reducing the incidence of disease and ensuring citizens a long and active life.

Article 43 ensures that citizens of the USSR have the right to maintenance in old age, in sickness, and in the event of complete or partial disability or loss of the breadwinner.

This right is guaranteed by social ensurance of workers and other employees, and collective farmers; by allowances for temporary disability; by the provision by the state or by collective farms of retirement pensions, disability pensions, and pensions for loss of the breadwinner; by care for the elderly and the disabled; and by other forms of social security.

The Constitution of the USSR ensures that citizens of the USSR of different sex, races and nationalities have equal rights, and grants citizens the right to associate in trade unions and other public organizations.

The Basic Principles of Labor Law of the USSR and Union republics make legal provisions for regulations and rules pertaining to Soviet labor laws.

The Basic Principles establish high standard of work and all-round protection of the rights of workers and other employees. These Principles oblige management to ensure safe and healthy working conditions in industry, promote novel safety layouts and devices that prevent industrial accidents, provide sanitary and hygienic conditions that reduce the incidence of occupational diseases, observe industrial safety and hygienic requirements during the construction and use of industrial buildings, structures and industrial equipment. By law, no industrial establishment that is newly built or substantially altered can be put in action unless it is approved by the competent authority executing state sanitary and technical supervision, trade union's technical and legal labor inspectorates, and the local trade union committee of the builder or contractor responsible for the project.

Management is held responsible for programs of instruction for workers and other employees on safety precautions, industrial hygiene, prevention of fire, and other safety rules and health regula-

tions. Management delegates its responsibility to foremen, safety engineers and other staff members that supervise the observance by workers and other employees of all the safety requirements contained in safety and health instructions.

Employment of women. In the country the safety rules are equal for men and women workers. In some cases, however, additional measures have to be taken to protect women from certain occupational risks because of their maternity functions.

Under labor laws, no woman may be employed or work on heavy jobs underground, under dangerous and unhealthy conditions (except for non-physical work in the medical and other services), also during the night except for certain economic sectors where night work is unavoidable and can be permitted as a temporary resort. Women entitled to maternity leaves and grants provided by the state social security enjoy a number of fringe benefits, such as additional non-paid leave, easier work, and are guaranteed employment and protected against dismissal.

Employment of persons under 18. The law places restrictions on the work of young persons in order to prevent their employment in dangerous occupations. Restrictions are also frequently placed on the employment of young persons in some kind of jobs which are clearly harmful to their health.

No person aged 15 can be employed or work except as permitted by the trade union committee. Employment of persons under 18 requires no term of probation; they cannot be employed on work underground or that is particularly heavy and dangerous, or on work that is liable to affect safety or health, or requires mature judgement for its safe performance. The persons under 18 should not be employed on work during the night, overtime or during holidays except for vocational training purposes in the cases, and under conditions to be specified by the competent authority. Safe working conditions imply correct working habits, and great care should be taken to teach them during the period of apprenticeship. Young persons enjoy annual paid holidays for one month during any time of the year, as they may so choose. Although employed for a shorter working week, such persons are entitled to a full pay as those working for the 41-hour week. No person under 18 can be dismissed except as approved by the local trade union committee or other competent authority, such as the panel for work with minors under a district community council (local soviet executive committee), and on the condition of subsequent employment. Additional benefits are provided for minors who work and study.

Employment of the partially disabled persons. Under labor laws, provisions for part-time employment are made specifically for partially disabled persons, such as invalids, retired persons, women who look after small children. On agreement with the management,

a shorter working day or incomplete working week can be established for such workers and employees before or during the period of employment with remuniration paid according to the amount of time worked or the amount of work done. Working under the conditions of part-time employment entails no limitations with respect to the annual paid holidays or length of service, and other rights of partially disabled workers and employees pertaining to their labor.

Invalid persons cannot be employed except as permitted by the medical authority and in accordance with the conditions for work and rest specified by that authority. The partially disabled are entitled to a number of benefits as regards vocational training length and time of holidays, medical treatment or sick-leave period.

The Basic Principles of Labor Law define the general duties of workers and employees who are obliged to work conscientiously in their chosen and socially useful occupation, strictly observe labor discipline, timely and precisely fulfil the instructions issued by management, raise labor productivity, improve product quality, observe technological requirements and instructions on safety and hygiene pertaining to their work, and preserve and protect socialist property.

Labor discipline can be enforced through persuation, encouragement and incentive measures, and is also ensured through the conscientious attitude of citizens toward labor. Evasion of socially useful work is incompatible with the principles of socialist society. Persons that do not show conscientious attitude to work bear disciplinary liability and can be corrected through measures of social pressure with or without punishment. Financial and moral incentives are used to encourage workers and other employees for good performance of their duties, successes in socialist emulation, for enhanced labor productivity, improved product quality, for innovations, and long, uninterrupted and irreproachable service.

Management of industrial undertakings and institutions establishes disciplinary liability of workers and other employees for the violation of labor discipline. Workers and other employees are made liable to compensate any direct damage they cause to the undertaking or institution for which they work. Basic financial liability may be up to one-third of a monthly pay. It may exceed one-third but cannot be more than the full amount of damage.

1.2. SAFETY LAWS AND REGULATIONS. PROMOTION AND SUPERVISION

Of the various means usually used to promote safety and health in industry, regulations and standards are the commonest.

Mention also should be made of inspection, technical, medical, physiological and statistical research, education, training, persua-

tion and safety measures within the individual industrial establishment.

Regulations and standards make specific the practical measures aimed at implementing the basic principles of labor laws.

It is customarily believed that any effective system of labor protection should rest on statutory requirements. These are all sorts of safety laws and regulations. Some people make a clear distinction between a law and a regulation. A law is passed by a parlament; a regulation is issued by a competent authority. In some cases it may have to be submitted to parlament before it becomes effective. This is a laborous process. There is a tendency to draft laws and confine them to general principles that may include a list of subjects on which a minister or other competent authority has the power to issue more detailed regulations. The list may be long enough to show how complicated labor legislation may become. However, laws and regulations by themselves can never be enough to achieve the highest standard of safety. They can only embody provisions that are enforceable without too much difficulty, and be applied by those responsible for doing it. They, as a rule, lay down a minimum standard of safety and often do not provide guidance as to how to achieve this standard.

Laws and regulations often have to combine technical and legal terminology, and as a result are difficult for a layman to understand. A useful practice is to issue booklets explaining the provisions of labor and safety laws in a simple language.

Regulations often use general terms which require an explanation to make their intention clear. A rule may indicate exactly what has to be done, but does not explain why and how it should be done, or a rule on a safety precaution may exactly indicate the purpose, but will give no information as to how to achieve this purpose, or against what hazard it is necessary. But practically, continuous changes taking place in many sectors of industry today make it impossible to avoid such general terms. Mentioning all details would result in a long unwieldy document, and should this be possible, such regulation may prove a serious impediment to new ideas on safety and new developments in accident prevention. In many cases, an authority is by all means needed to give a valid interpretation of labor laws or safety regulations.

Regulations are mandatory prescriptions concerning such matters as the general working conditions, the design, construction, maintenance, inspection, testing and operation of production equipment, the duties of management and workers, training, medical supervision, first aid and medical examination. They may be classified as follows.

General regulations that apply to all branches of the economy.

Intersectorial regulations applicable solely to some of the economic

sectors, industries, or certain types of equipment for which the safety and hygienic requirements contained in the regulations are common.

Sectorial regulations that are valid for an industrial sector of the economy or industry and are mandatory to follow by all the production undertakings, plants or factories of a given sector or industry.

Standardization is the laying-down of official, semi-official and unofficial standards concerning, for instance, the general requirements for the safe construction of certain types of equipment and equipment parts, safe and hygienic practices, or personal protective devices. These standards form a system or a code of interrelated safety requirements designed to ensure safe and healthy working conditions.

Standards of safety and hygiene may be grouped as follows:

(1) *Basic national standards* that establish the definition, purpose, content, classification and designation of the requirements being standardized; terminology of health safety; classification of industrial hazards.

(2) *General national standards of safe and hygienic requirements* distinguished by the type of industrial hazard. These standards specify safe (maximum permissible) values for the rating of the desired environmental parameters; requirements for methods of measuring these parameters; safety requirements for work with materials or substances that are classed as noxious, or dangerous for human life and health.

(3) *General standards of safe construction of industrial equipment* and equipment parts, means of control, alarm and protective devices and layouts, and the methods for enforcing such requirements.

(4) *General standards of safe munufacturing processes* that lay down the safe positions of technological systems, safe operating conditions for industrial equipment and machinery, requirements for using protective equipment, and methods for enforcing these requirements.

(5) *Standards for the means of protection* that prescribe the basic parameters of construction, operation and hygiene for the various means of collective and personal protection, and methods of testing and approving such means.

It has long been realized that labor safety legislation would be ineffective or useless unless understood, obeyed and complied with. If in practice safety rules, instructions and regulations are ignored there is an apparent need to enforce and supervise their compliance and observance.

In accordance with the Basic Principles of Labor Law the supervisory functions of enforcing of all labor laws, such as dealing with health safety, working hours, days of rest, protection of female and adolescent labor, minimum wages and social conditions in the country, are entrusted to state bodies, such as:

— specialized labor protection agencies and similar-status inspectorates (inspection services) for the various technical matters. These are given an independent status and a standard of remuneration that secure their freedom from any improper external influences; specialization is necessary to make inspection work effective in the face of the ever-increasing complexity of technology; and

— trade unions, namely their technical and legal labor inspectorates.

In view of the difficult scientific and technical questions which arise in modern industries it is recommended that such state and public enforcing agencies include experts having competent medical, engineering, electrical or other scientific training and practical experience. It is important that the trade unions inspectors be technically competent to command the respect of the people with whom they have to deal.

Executive committees of the local bodies of state authority and administration (soviets or councils of people's deputies) are held responsible for the supervision of compliance with labor laws within the area under their jurisdiction.

Ministries and other government departments exercise intersectorial supervision of compliance with labor laws in industrial undertakings and institutions they hold under their authority.

The Procurator Office of the USSR is responsible for the general supervision of compliance with the labor laws throughout the country.

It will be clear that labor protection, accident prevention and industrial health require cooperation of many kinds of people such as legislators, government officials, technologists, physicians, psychologists, statisticians, teachers and certainly the management and the workers themselves. In addition, there must be an ample amount of state and public agencies drawn into the supervision and enforcement of labor safety laws and regulations.

1.3. HEALTH SAFETY IN THE INDUSTRIAL UNDERTAKING

The role of management. The saying "safety begins at the top" clearly states the essential condition for successful safety work in an industrial undertaking. Safety engineers, foremen and other supervisory staff members can never achieve good results if top management does not take the lead in promoting and maintaining high standard of safety. The role of management must be manifest in all that have to do with the working environment and the people in the undertaking. Management has to organize production process efficiently combining a maximum of production with a minimum of cost and should treat safety not as an extra but as part of the process itself. The management concern for safety must be attested to

(a) provision and maintenance of safe working conditions in technological processes and manufacturing operations;

(b) carrying out in good time practical measures to promote safety and industrial hygiene, mechanize and automate processes and jobs that are classed as heavy, harmful or dangerous;

(c) provision and maintenance of the normal temperature and humidity and clean air (adequate air-conditioning) in workrooms;

(d) incalcating to workers, operating engineers and other technical staff the correct working habits and safe working methods by adequate vocational training, regular instruction courses, briefings and through other means;

(e) provision for workers with the necessary working clothes and personal protective equipment.

Organizationally, the management (director and chief engineer) delegates the responsibility for safety activities in the undertaking further down to the foremen in production departments. The enforcement of safety measures depends to a greater extent on the foreman who for the workers represents the management. He has to see that the intentions and orders of the management are carried out by exercising his authority and influence.

Among the other supervisory officials, the management has a bureau or office for accident prevention, or a safety engineer who is the general adviser on safety. The duties of the safety engineer or head of accident prevention bureau are, in short, to eliminate hazards, and will include the following:

(a) formulating and supervising the implementation of the industry's general accident prevention policy;

(b) recommending measures to improve and make safer working conditions, arranging and supervising safety training in courses of instruction concerning safety precautions and safe working methods;

(c) serving on the safety committee to check the knowledge of safety laws, regulations and correct working habits of the operating engineers and other technical staff members;

(d) investigating accidents associated with production;

(e) reporting to and advising management on all safety matters, such as the planning of new buildings or alteration and maintenance of the old ones, the acquisition of new machines and other equipment, the arrangement for the testing, maintenance and repair of equipment;

(f) drawing up safety instructions, guides, notices, placards and other kind of safety literature; setting up safety study-rooms, directing safety activities, such as competitions, exhibitions, and safety propaganda campaigns;

(g) keeping accident recording and statistics by causes, and types of accident, accounting reports on the spendings from funds allocated for accident-prevention measures.

Other duties and matters on which the safety engineer should report to and advise management will include giving guidance to supervisory staff, examining plants, equipment, processes and working methods, fire-protection and similar activities, such as drills, safety devices and personal protective equipment.

In general, the accident prevention bureau or safety engineer should do everything they can to bring the undertaking into a safe condition and keep it so, and to eliminate unsafe working conditions.

The safety engineer has a special status when the work to be done calls for extraordinary precautions. Such work should not start until he has given his permission. As a rule he has to provide the department (in charge of the work) with a written permit indicating the precautions to be taken, and to supervise it closely while it is going.

High standard of safety can never be achieved without a thorough instruction and training on safety and health risks, hygiene, care of clothing, maintenance, and care of machines, tools, materials and equipment inside the undertaking.

The safe operation of some installations that present hazards and risks to human life and health depends on the competency of the personnel responsible for operating them. Such installations can only be operated by holders of official certificate of competency. The regulations covering the qualification examination, certification and employment of such workers may be very comprehensive. Competence should be proved and certified each year.

In departments where risks and hazards are increased and processes are extremely complicated, each worker after a course of practical training in which he acquires the necessary routine in safe working methods should pass a test of competency in regard to the safety aspect of work.

Training for a specifically dangerous job must be supplemented with an adequate instruction by the safety instructor, charge-hand or foreman.

Each industrial undertaking carries out a safety instruction program for all the workers and other employees. The program usually provides for:

— *introductory instruction* or briefing. It is normally given to each newcomer by the safety engineer or, in his absence, by other competent person. Introducing a new worker to the undertaking requires special care. The newcomer should be acquainted with the character of production, how the factory is run, the new environment, and told what is expected of him. He should also have the hazards explained to him and be shown how he can avoid them by correct working methods and obeying safety rules. In addition, the newcomer should have the internal regulations explained to him and be told what is

expected of him in regard to the general requirements of industrial and personal hygiene;

— *first-job instruction* or *primary* instruction. Job instructors, charge-hands and foremen usually analyse the job before they give instruction to newcomers or other workers to whom the job, machine or equipment is new. They particularly identify the various difficulties and hazards which their trainees should learn to deal with. The newcomers are explained clearly and fully the details of

(a) design features of equipment or machine-tool he is supposed to operate;

(b) proper and safe housekeeping habits and order in his workplace;

(c) safety instruction manuals for the given machine, equipment or operation (as far as these instructions are of immediate concern to him);

(d) safe methods of work;

(e) risks of accident that may arise from the deviation from safe methods. Care should be taken to ensure that the workers really understand them.

In addition to the first-job instruction it is obligatory that the trainees in particularly hazardous occupation would have (depending on job complexity) a "follow-up" period of 6 to 10 days before he begins to work independently, to try himself to make sure that he has understood and developed the necessary routine and work habits;

— *regular instruction* on safe methods and practices which is mandatory and given every 3 to 6 months to all workers and other employees regardless of their skill and length of service in the given occupation; and

— *off-schedule instruction* may be needed if:

(a) manufacturing process and equipment have been altered or similar circumstances have occurred;

(b) previous instruction to the workers has proved inadequate resulting in an accident or occupational disease;

(c) safety rules and instructions have been ignored or violated.

For each new worker the personnel department issues a check-form, the newcomer and the instructor should sign for each instruction procedure that regularly follows. No worker or other employee can be admitted to work unless he has received instruction of immediate concern to him, and proved his knowledge of working methods before the safety testing commission. The safety-work register is kept to include all the entries of all kinds of instruction, briefings the worker has attended.

Particular emphasis is placed today on training the responsible supervisory staff and middle management personnel in the requirements of job safety, application of safe practices to work at refresher

courses whose curriculum, time and length are approved by the superior body.

Safety officials of ministerial and departmental labor protection services have to refresh their knowledge in such matters once in three years at similar courses.

Some other aspects of accident prevention are propaganda measures. A well equipped accident-prevention center can be very helpful

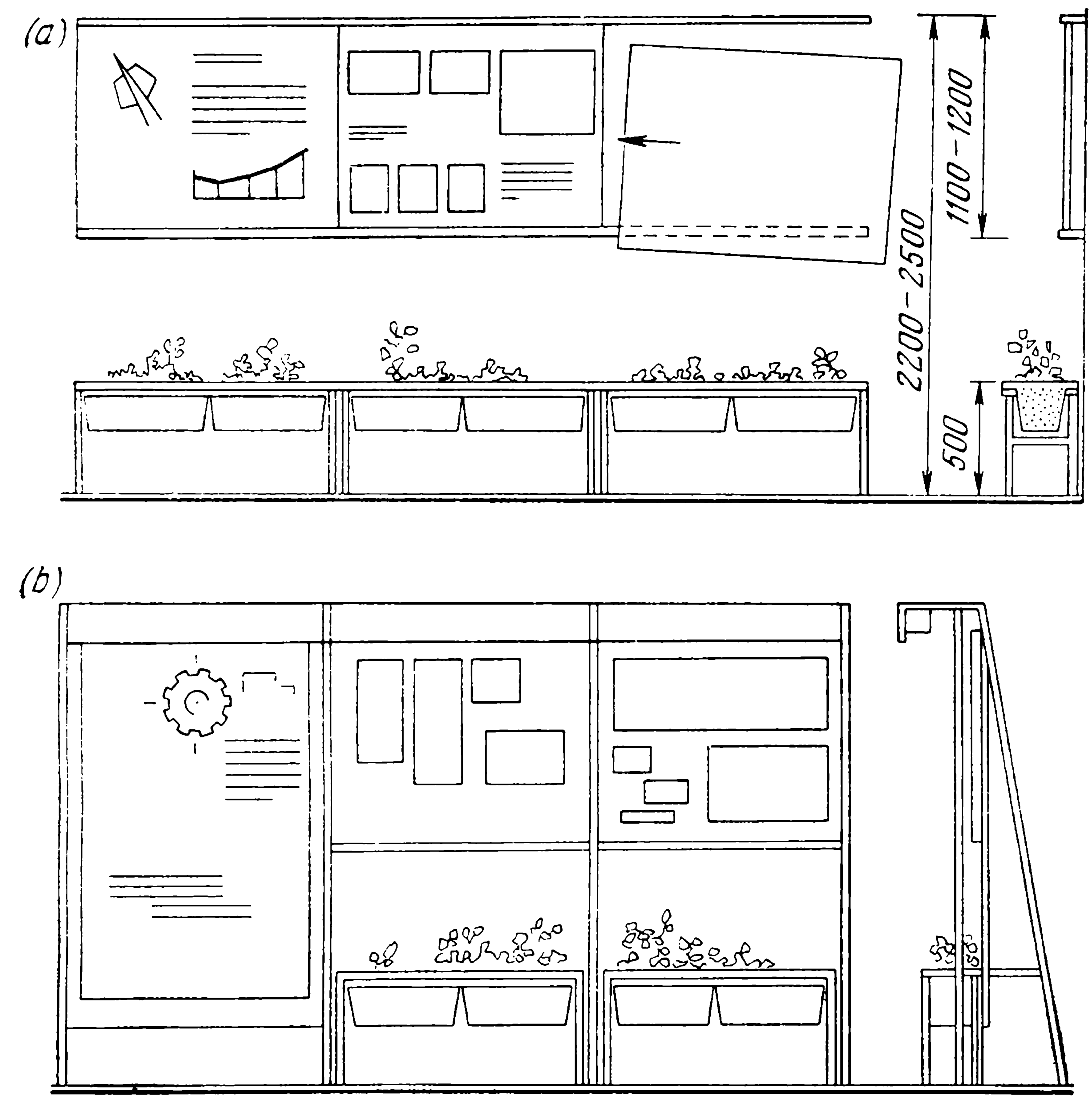

Fig. 2. Safety propaganda bulletin boards
(a) wall-poster; (b) poster-stand

in promoting safety and incalcating "safety-mindedness". Such center can set up safety exhibitions, organize film or slide shows, dissiminate safety literature, organize talks, lectures and conferences, competitions, and launch intensive safety drives or campaigns.

There are all sorts of posters printed by publishers or drawn inside the undertaking, and each may help to promote safety in a different way. One type of poster, known as the positive poster, shows the advantages of caution; another, known as the negative poster, illustrates the consequences of carelessness. Yet another type of

poster shows photographs, while yet other includes drawings. Bulletin boards for posters should be agreeable to the eye, put in prominent places and properly maintained. They should be glass-fronted and well-lighted as to stimulate the interest of the workers in the boards and notices. As an accessory means of improving safety, the poster helpful for instructional purposes can be used to stimulate workers to think more about safety (Fig. 2).

Colors, notices, signs and labels may also be used for a variety of purposes in the interests of safety. Safety color codes (orange-yellow, red, green, yellow-black stripes) are used to identify danger spots, fire-protection and first-aid equipment. Attractive colors for walls, ceilings, equipment can produce a good psychological effect.

Notices and signs convey instructions, warnings or general information. They are not a general substitute for protective measures but a useful supplement.

Dangerous substances and the containers for such materials should be properly labelled. Many accidents can be avoided if labels on containers bear symbols indicating that the contents are dangerous, and a text added to such symbols indicates the name of substance, description of risk, main precautions, and the first-aid recommendations or other simple measure to be taken in the case of misuse or emergency.

1.4. ACCIDENT INVESTIGATION AND STATISTICS

The possible causes and types of accidents within the undertaking are manifold and may arise from unsafe mechanical equipment, environmental condition, hazardous arrangements around the workplace, unsafe acts committed.

The industrial (occupational) accident can be defined as an undesirable event that results in a certain length of disability and stoppage of work and time loss due to the effect of a production-related dangerous factor or a combination of such factors. According to other authors, an occupational accident is presently regarded as an index or a symptom of disfunction in a system formed by a production unit, such as a factory, a workshop, a shift or a workplace.

The *injury* is an external damage to the human body, disturbance or disfunction resulted from an accident.

By cause, injuries can be *mechanical* (bruise, cuts, tissue ruptures, breakages, etc.), *thermal* (shock, burn, frost-bite), *chemical* (burn, acute intoxication and poisoning), *radiated* (tissue regeneration, changes in the hematopoietic system), *combined* (the effect of more than one causative factor with various consequences). The result of accidents (which may cause serious, minor or no injury) may be

the cases of temporary or permanent disablement or the fatal cases.

The occupational disease is an unhealthy condition caused to the person by exposure to unsafe working conditions.

The occupational poisoning is a partial case of occupational disease. Continuous or long exposure to relatively small amounts of noxious or poisonous substances is conducive to a *chronic poisoning*. Accidental poisoning called the *acute intoxication* is caused by penetration into the body of a large amount of noxious substances. This type of poisoning is considered and to be reported as an accident.

Injuries and occupational diseases should not be looked upon as inevitable and inherent in the production process. Many of them can be prevented through proper and adequate safety measures. The factors of accident causation are many and they vary from one sector of industry to another. Some are purely industrial, others more personal and psychological. It is therefore difficult to develop a method of classification and recording the very many types of accidents which occur in the industry.

The management of the undertaking is obliged to investigate each accident within 24 h (serious, fatal cases and those involving more than one person should be investigated immediately). If the accident has caused time loss (disablement for no less than one working day) the accident-investigation form must be filled in a prescribed manner and filed for statistical purposes or other action. The accident-investigation form is the principal document that provides essential information needed for the compilation of accident statistics, statistical analysis of accidents and injuries by causes; the identification of primary causes as the most easily preventable circumstance in the absence of which the accident could not have happened, i.e. for the framing of the accident prevention policy.

Before suitable precautions against accident can be taken it is necessary to know how exactly and why they occurred. This knowledge can be obtained by a careful examination of each case. An accident investigation should be made on the site by the foreman, senior labor-safety inspector of the department, and the safety engineer who reports the case in a written form to the undertaking's chief engineer. He studies the case and approves of the suggested preventive measures, and the director issues an order to eliminate the cause and appoints the responsible persons and fixes the dates within which the order is to be executed.

Various accident statistic data are compiled for each undertaking to result in an annual report on persons injured in accidents, associated and nonassociated with the production process. The report differentiates accidents by type and cause and indicates the capital spendings for labor safety measures.

Associated accidents are ones that occurred to victims inside the gates of the undertaking, construction site, institution or establishment; or outside during work on job assignments by management's order, or during the personnel carriage to and from the place of work by a transport vehicle belonging to the undertaking. Reportable are also accidents that occurred during the working day (inclusive of fixed breaks), immediately before and after work, as well as during work overtime, day-off and holidays.

Nonassociated accidents are ones through which persons may fall victim as a result of unauthorized fabrication of certain objects in the person's own interest, misuse of the undertaking's transport facilities, horseplay, misappropriation of materials, tools, or intoxication other than one caused by alcoholic, aromatic, narcotic and similar substances used in the manufacturing process.

By law, the production management is made responsible for the adequate and timely investigation, compilation and reporting on accidents. The trade union sees that accidents are investigated and reported properly, in due time, and the measures to eliminate the causes or causative factors of accidents are implemented.

Those who violate associated-accident investigation procedures and record-keeping regulations are made answerable for these violations.

A matter of special concern is the investigation and compilation of cases of industrial accidents that involve more than one victim, cases of high-degree of accident severity, and fatal cases. Such accidents are made special cases of investigation.

Accident statistics are essential for planning accident-prevention activities and assessing their effectiveness. The simplest statistical information refers to the total number of accidents. For accident frequency rates, the number of accidents is normally studied in relation to the number of hours of risky exposure. Accident severity rates require in addition the amount of time loss.

Injury rates are basically calculated by two methods, the statistical and job-safety analysis methods.

The statistical method is based on the total number of accidents (serious, minor and near-accidents) compiled for a certain period of time. The method clearly indicates the number and severity of injuries caused by accidents by providing the coefficients of rates of accident frequency and severity.

The frequency coefficient (F) determines the number of accidents for each thousand man-hour exposure and can be expressed by the following formula:

$$F = T\,1\,000/P$$

where T is the number of injuries for a given period; P is the total man-hours of exposure.

The mere number of accidents is not a very good measure of the effect of accidents. The severity rate gives a better idea of the situation.

The severity coefficient (S) determines the average time loss (length of disability) due to accidents per one accident for a given period and can be expressed as

$$S = D/T$$

where D is the time loss, in days, due to all accidents that occurred for the given period.

It will be noted that a serious accident has a considerable effect on the accident severity rate but it does not greatly affect the accident frequency rate. The coefficients of accident frequency and severity give valuable information on the safety situation in the undertaking both absolutely and in comparison with other undertakings within the industry. More importantly, they are very useful in planning the immediate measures to control accidents in the undertaking.

The statistical method is helpful in showing the distribution of accidents by occupation, length of service, age or sex, cause or type, nature of injury, equipment involved, and by organizational and technical factors.

The method of job-safety analysis helps identify fully the causes and types of accidents. The method involves a detailed examination of individual workplaces and installations in the department with a view to identifying the risks or danger spots and to develop a system of preventive measures and safety precautions. The analysis isolates every single operation in a job, examines the hazards of each and indicates what should be done about them. It also involves the examination of work permits, work methods and practices, technological processes, principal and auxiliary equipment, work clothings, etc. Just as productivity can benefit from work study or job analysis, so can safety benefit from job safety analysis. More to that, the two are intimately grown together. Job-safety analysis singly or as part of job analysis can do much to improve safety and eliminate hazards of a job or process.

Accident investigation and job-safety analysis yield valuable information for safer construction of equipment, machine-tools and other appliances, alteration of production processes, elimination of unsafe operation, and for improving the organization of labor.

1.5. RESPONSIBILITY FOR VIOLATION OF LABOR LAWS

Officials found guilty of violating labor laws, labor protection rules, collective bargains or agreements on industrial safety and labor protection and of interfering with trade unions labor protec-

tion activities are held responsible for their actions and may be subjected to penalty in the term of administrative, disciplinary, financial and criminal liability in accordance with Soviet law.

In Soviet law, **disciplinary liability** implies punishment or blame imposed on the violator by the management in the form of warning, reprimand, transfer to a lower-payed job or demotion for a term of up to 3 months, and dismissal.

Punishment imposed onto officials bearing disciplinary liability in line of subordination, beside the above forms of punishment (exclusive of reprimand), includes demotion for a term of up to 12 months or a dismissal for a serious violation of their duties.

Administrative liability implies monetary penalties or fines imposed by state supervision agency on violators of labor laws, rules and regulations of safety and industrial hygiene.

Financial liability is compensation by the violator for losses the undertaking or social security agency has run into by payments necessary for the health rehabilitation of the victim. An official person found guilty of unlawful dismissal or transfer of a person to a lower-payed job may, by decision of court, be made liable to compensate the undertaking for the time loss (absenteism) or time the person was on the lower-payed job. The liability may not be more than the pay for three months.

Criminal liability is sanctions for violating safety rules, industrial hygiene regulations, and labor laws if such violation has resulted in or might have brought about accidents, or has entailed other serious consequences.

Ignorance of the law is no grounds for denial or withdraw of mitigation of penalties for violation of industrial safety.

CHAPTER 2

Industrial Environment: Health Hazards and Their Prevention

Here and after the following definitions are used:

Unsafe production factor means an industrial agency or agency part which under certain conditions may invite an injury or disease.

Harmful element means a substance which in contact with the human body is likely to cause, during employment and long after, identifiable by modern methods, injuries and diseases or likely damage to the health of the present and future generations. Harmful elements may be toxic, corrosive and irritating.

Excessive dusting and gassing of the atmosphere in production areas are classified as an unsafe production factor.

As a factor of safety in the physical environment of the worker clean air in a combination with optimum temperature, relative humidity and velocity is essential. The air in a manufacturing undertaking is, as a rule, polluted by harmful gases, flammable vapors and noxious dusts. Generally, the working atmosphere may be considerably heated and humidified by heat and moisture produced by different manufacturing processes, machine-tools and other industrial equipment, and by the occupants themselves.

The sanitary regulations for the design of industrial establishments prescribe maximum safe limits for the airborne harmful elements as well as other safe characteristics for the ambient air in the work zone. Unsafe air parameters can be brought to safe levels by using safe processes designed so that all noxious releases into the air are avoided, also by safe construction of industrial equipment, its proper position, operation and maintenance. Noxious dusts and flammable vapors in the working atmosphere can be diluted to safe limits or removed altogether by means of general and exhaust ventilation. Air conditioning can prevent excessive cold and excessive heat which are both conducive to accidents.

Among many other things, workers' behavior reflects the physical environment. Adequate atmospheric environment is likely to give the worker bodily comfort, peace of mind, increase work efficiency and, as such, is important factor of both production and health safety.

2.1. CONTAMINATION OF AIR AND CONTAMINANTS

Much dust, toxic and corrosive vapors and gases get into the air of the hot and cold forging departments.

In foundries, preparation of sand mold and core sand, descaling and chopping of castings, and other operations produce dust in large quantities. Smelting, metal casting, laddle baking and mould casting give off much toxic substances into the working environment in the department.

Excessive fumes, soot and harmful gases in the atmosphere of forge shops can largely be due to inadequate exhaust ventilation or incomplete removal of combustion products, gaseous carbon oxide and sulfur dioxide, in particular.

Dust, noxious vapors and gases are produced into the atmosphere of heat-treating shops during casehardening operations that involve such chemical processes as carburizing, cyaniding and nitriding. Casehardening may thus be effected by a dry method in a mixture of pulverized char-coal and soda, and by a wet method in baths with sodium or potassium cyanide, or in a flow of ammonium gas passed through a furnace.

The physical environment in machine-shops is likely to deteriorate from excessive dust produced by the various operations such as turning, grinding, shaping, etc. The rate of dust formation depends on the kind of metal, type of tool (abrasive or other type), method of metal-working (dry or wet), availability and design of dust-evacuating devices.

Operation of the various sorts of machine-tools involves extensive use of lubricant-coolants of various chemical composition. Splashed and evaporized lubricant-coolant, when coming in contact with the cutting tool that normally heats to a temperature of some hundred degrees centigrade, causes the formation of oily aerosols and various kinds of vapor-gas mists polluting the ambient air. Inhalation of such harmful elements is likely to irritate the respiratory organs, cause respiratory infirmity, or some pathological condition to the lung and other systems of the human body.

Welding, electroplating and painting operations are common for assembling departments. Welding, for example, gives up toxic vapors and aerosols of complex composition. Electroplating is a wet process effected either in an acid (sulfides of nickel, zink and copper), or in an alkaline (cyanides of copper, zink, cadmium or aluminium) electrolyte. Before the workpieces are submerged in electrolyte baths they are treated with solvents, or pickled with diluted acids to remove grease, oxides and various oily contaminants. The process of electroplating is accompanied by releases of

multitudes of gaseous bubbles (of hydrogen, oxygen, etc.) with harmful vapors and minute droplets of electrolyte.

Before a paint-coat is applied, workpieces are mechanically cleaned with brushes, abrasive (emery) paper, or degreased with solvents and alkaline solutions. Painting materials and varnishes may be applied as sprays, atomized by compressed air, or applied electrostatically, and by other known methods. Unless exhaust ventilation is properly designed and installed undue quantities of harmful elements in the form of dust, vapors, fumes or gases are likely to enter the worker's breathing zone.

Manufacturing industries make wide use of plastic materials. Plastics that contain nitroacrylic acid, phenol, diphenyl and other harmful substances produce noxious vapors, gases and dust when cut, drilled formed or otherwise worked mechanically.

Harmful elements (vapors, gases, dust) contained in the atmosphere of workrooms are likely to enter the human body through respiratory organs and gastroenteric tract and, under certain conditions, cause acute intoxications or chronic poisoning.

One harmful element commonly found in the working atmosphere of industrial undertakings is dust, the very fine particles of solid materials. Dust which for some time is able to remain suspended in the air (airborne dust) is called the *aerosol* versus the *aerogel* which is the lodged or settled dust. Dust is very harmful to the respiratory organs and the lungs. Harmful elements in the form of dust may cause a pathological lung condition known as pneumoconiosis. One known condition of pneumoconiosis is fibrosis or pneumosclerosis (substitution of lung tissue by connective tissue). The commonest of the pneumoconiosis is silicosis, which is caused by silica dust.

Depending on the nature and physical shape of dust particles, respirable dust may seriously affect the skin and eyes and lead to accidents of which eye accidents are too many. It is customary to classify dust by toxicity and dispersion. Dust formed from harmful elements such as lead, manganese and chrome is referred to toxic or noxious dust. In contact with physiological fluids (saliva or mucose membranes) such dusts produce poisonous solutions that are likely to cause acute intoxication or chronic poisoning. The harmful effect of dust increases with its subsequent concentrations. The level of dust in the air is determined by its mass content in milligram per cubic meter (mg/m^3), or the number of dust particles per cubic centimeter.

By dispersion (fineniness), dusts are classed into:

(a) *coarse dust* comprising particles larger than 10 μm which free-fall speed in still air tends to accelerate the nearer it comes to the ground surface (i.e. particle's pull of gravity exceeds its force of drag friction in the ambient);

(b) *medium-sized dust* consisting of particles sized from 10 to 5 μm which speed of free-fall in still air is slow; and

(c) *fine dust*, and *smoke* which particles that are smaller than 5 μm almost never lodge but disperse rapidly in the ambient. Fine dust is most harmful to health. When inhailed, fine dust finds practically no difficulty in penetrating into the lungs, but particles of coarse and medium-sized dust are normally trapped in the upper respiratory tract.

The shape of dust particles is an important injurous factor. Polyhedron is the commonest shape of dust particles of which many have

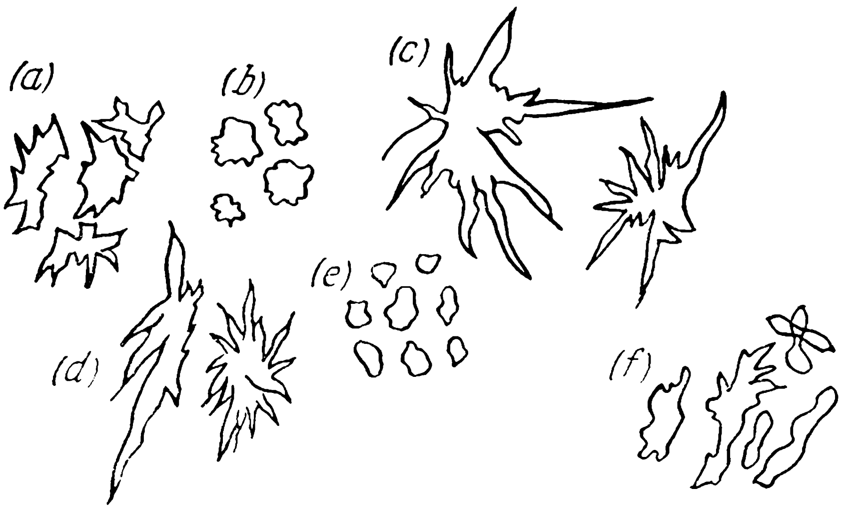

Fig. 3. Shape of dust particles of various materials
(*a*) iron; (*b*) cast-iron; (*c*) pearl; (*d*) glass; (*e*) cork; (*f*) paper

needle-pointed or hooked protrusions (Fig. 3). When inhailed, such particles are likely to cause injury to the respiratory tract tissues. The injured cellular tissue is an easy target for infection or other pathogens which cause inflammation.

One chief aim of industrial hygiene is a working atmosphere in which dusty and gaseous contaminants are removed, diluted and, as far as practicable, maintained within the safe limits so as not to cause, directly or indirectly, any harm to human health even at long exposure.

The National standard classifies harmful elements contained in raw materials, finished products, unfinished articles, by-products and industrial wastes, and establishes general safety precautions to be observed during their production, use and storage. By hazard to human health, the standard groups harmful elements under four classes, namely:

Class 1—extremely injurous elements;
Class 2—highly injurous elements;
Class 3—injurous elements;
Class 4—almost noninjurous elements.

Each class is delimited according to the maximum safe concentration (MSC) and average lethal concentration (LC) (Table 1).

Table 1

Factor	Concentration by hazard class, mg/m³			
	1	2	3	4
MSC	max. 0.1	0.1-10	1.1-10.0	min. 10 000
LC	max. 500	500-5000	5001-50 000	min. 50 000

The levels of harmful elements in the working atmosphere should be checked continuously for Class 1 substances, and periodically for Classes 2, 3 and 4, and must not exceed the MSC specified for each element by the standard. The National standard establishes MSC for more than 700 harmful elements of which some, most common for the manufacturing industries, are listed in Table 2. Where

Table 2

Substance	MSC, mg/m³	Hazard class
Acrolein	0.2	2
Acetone	200	4
Benzine (calculated as C)	300	4
Commercial petrol (calculated as C)	100	4
Benzene	5	2
Copper	1	2
Mercury (metallic)	0.01	1
Lead and its inorganic compounds	0.01	1
Caustic soda	2	3
Sulfuric acid	1	2
Hydrochloric acid	5	2
Methyl alcohol (methanol)	5	3
Antimony, metallic dust	0.5	2
Carbon dioxide	20	4
Chlorine	1	2
Caustic alkali, solutions (calculated as NaOH)	0.5	2
Dust, with more than 70% SiO_2	1	3
Dust, with less than 2% SiO_2	10	4

the CO levels in the working atmosphere are elevated, for example, to 50, 100 and 200 mg/m^3, safety precaution requires that the duration of work be limited to not more than one hour, half an hour and fifteen minutes, respectively, i.e. short-time exposure limits come in effect. Subsequent work in such physical environments can be resumed at least after two-hour interruption.

Where the working atmosphere contains several harmful elements of a similar action, the standard requires that the sum of ratios of each element's apparent level (C_1, C_2 . . . C_n) to the element's

MSC (MSC_1, MSC_2 . . . MSC_n) be not greater than unity:

$$C_1/MSC_1 + C_2/MSC_2 + \ldots + C_n/MSC_n \leqslant 1$$

Where the air is polluted with more than one harmful substance each acting in a different way, the joint effect of these elements is not calculated and each element's MSC remains as specified by the standard.

Maximum safe concentrations for harmful airborne elements apply to every workplace, be it a workroom, open grounds, or a transport facility.

Safety precautions against the effect of harmful elements should include lung and respiratory protection measures of which the use of personal protective equipment and a course of training and instruction are most practicable.

The maximum safe concentrations of harmful elements in the atmosphere of populated areas are considerably lower than the MSCs set for production areas. In all cases, the level of harmful substances in the air drawn through forced or natural ventilation into residential and public buildings should not be more than 30% of the MSCs specified for the atmosphere of industrial undertakings.

Effluent air with undue harmful or odorous substances should be cleaned to safe limits specified for the atmosphere of industrial buildings. Dust content in effluent air is permitted to be several times the MSC for dust in the working atmosphere inside industrial buildings. With rates of effluent air discharge exceeding 15 000 m^3/h, its dust content can be determined using the expression:

$$C_1 = 100K$$

where K, depending on dust MSC in the air of production area, can take on any of the following values:

MSC, mg/m^3	K
2 and less	0.3
from 2 to 4	0.6
from 4 to 6	0.8
6 and more	1.0

If the rate of effluent discharge is up to 15 000 m^3/h, we apply the formula $C_2 = (160 - 4h)\,K$, where h is the rate of effluent discharge, in thousand m^3/h.

2.2. MICROCLIMATE IN PRODUCTION AREAS. CLIMATIC HAZARDS AND THEIR PREVENTION

Production quarter means a closed space within specialized buildings and structures in which persons, continuously (during the working day) or regularly (in shifts), perform their work duties

associated with both productive and unproductive spheres of industry.

Work zone means space 2 m high above the floor level of production area or any elevated platform that encompasses all sites of permanent or temporary workplaces. Floor area which a person occupies during half of his working time or for more than 2 h continuously is regarded as his *permanent workplace*. If a job or occupation requires movement about the work zone, this last is considered the permanent workplace.

Microclimate of a production quarter means climatic conditions created and controlled artificially for a limited production area (department, workshop, room, etc.) characterized by a set of physical factors and their combinations (temperature, humidity, air movement, atmospheric pressure, lightening, etc.) which exert a certain influence on the human body, its working capacity, person's peace of mind, well-being, humor and health condition.

Light job (Class I) means work that is not associated with the lifting or handling loads and can be performed when sitting, standing or whilst moving and causes no systematic physical strain. Performance requires an energy of up to 172 J/s;

Medium-heavy job (Class IIa) means work performed when sitting, standing or whilst moving and involves no handling of loads. Energy requirement is between 172 and 232 J/s; Class IIb job is associated with motion and handling small loads (up to 10 kg). Energy requirement ranges from 232 to 293 J/s; and

Heavy job (Class III) means work associated with a systematical physical strain from handling loads (above 10 kg). Energy requirement exceeds 293 J/s.

Other factor of safety in the working environment is an adequate combination of air temperature, relative humidity, velocity, and barometric pressure—all conducive to the comfortable microclimate in the work zone. Environmental comfort is also an important production factor. Any discomfort about the work zone ambiency is likely to lower efficiency, cause premature fatigue, carelessness or inattentiveness which may lead to accidents, injury, infirmity, or occupational disease.

Air temperature. Temperature of the ambient air has a great influence on the worker's physical state and his work efficiency. Air conditioning can prevent excessive cold and heat because high temperatures in combination with high degree of humidity cause premature fatigue, overheating and excessive sweating—all conducive to accidents.

Interestingly, air temperature appears to increase 1 to 2°C and even more with every subsequent meter above the floor level and may reach 40-50°C near the ceiling. This must be taken into account in framing safety policy for departments having elevated pads, platforms and cabins for maintaining large-size installations, machine-tools, or for operating over-head traveling cranes.

Low temperatures are likely to cause local or general cooling of the human body and lead to catarrhal and other respiratory disorders. Working on machines with cold hands may result in a lesser degree of accuracy and accidental contact with machine knives or cutters.

Air humidity. Humidity is an important environmental characteristic which determines the optimum safe temperature in the work zone, the other being the physical effort that the work may demand.

The air remains humidified, no matter how dry it feels, by water vapors it invariably contains. The concept of air humidity differentiates:

maximum humidity which is the uppermost quantity of moisture that may be held in the air at a given temperature;

absolute humidity, that is the actual quantity of moisture held in the air at a given temperature; and

relative humidity, defined as the percentage ratio of the absolute humidity to the maximum humidity at a given temperature. The hygienic and sanitary standards refer always to relative humidity as a factor conducive to the safe working environment.

Excess humidity may result from various processes that produce water vapors into the working atmosphere during the heating and mechanical agitation of hot processes-waters in various baths or washing machines. Certain amount of moisture adds up as it evolves from the human body. It is generally accepted that the optimum relative humidity is 60 to 40%.

Excessive saturation of the air with water vapors prevents vaporization of moisture from the skin and the lungs which causes much discomfort and reduces work efficiency. Vaporization of excess moisture that results from hyperhydrosis plays an important part in heat transfer from the human body, and particularly so when jobs classed as medium-heavy and heavy have to be performed in an atmosphere heated to 26°C and higher. Vaporization heat transfer brings relief and prevents unnecessary fatigue and discomfort. Likewise, a decreased level of humidity, e.g., up to 20%, also brings much discomfort to the worker: he feels very dry in the upper respiratory tract and the mucose membranes. The hygienic standards establish the safe levels of relative humidity in relation to temperature and circulating velocity of the air.

Air velocity. Movement of the air about the work zone is an important factor of a comfortable working environment in a manufacturing undertaking. It will be noted that the human body feels slight movements of the air at flow velocities about 0.15 m/s, and at temperatures up to 36°C the effect of movement is refreshing, while at 40°C and higher, it is suppressing.

It is commonly believed that the optimum safe temperature about

the workplace in a temperate climate is 20°C. It will be however more correct to say that the optimum safe temperature depends on a number of factors including relative humidity, physical effort, air movement, etc. In other words, all the environmental factors are closely interrelated. That is why the human body responds so readily to changes in any of these factors. For example, it feels equally warm in still air if the relation of temperature to humidity is as follows:

temperature, °C	17.8	18.3	20.7	22.3
relative humidity, %	100.0	90.0	50.0	30.0

The human sensation of the ambient comfort can be expressed by the effective (equivalent) temperature determined empirically, and which, together with the zone of comfort, may be found from the nomogram in Fig. 4.

Thermal balance and heat control mechanism. Man finds himself in a constant thermal interaction with the environment. Physiologically, the human body is designed so that its normal functioning is possible only if the heat it generates is transferred to the ambient, and if this last is able to absort all the amount of heat released from the body. When these conditions are met, too much heat or cold will cause no trouble.

The transfer of heat Q from the human body occurs usually by conduction Q_{cond}, convection Q_{conv}, radiation Q_{rad}, vaporization Q_{vap}. The balance $Q = Q_{cond} + Q_{conv} + Q_{rad} + Q_{vap}$ gives man bodily comfort.

The capacity of human organism to maintain a constant body temperature of 36.6°C (to within ±0.5°), regardless of external conditions and internal efforts, by heat exchange is known as the *heat control.* Through the mechanism of heat control the body keeps balance between the heat it generates and the heat lost due to physical and life support efforts. The amount of heat generated by the body varies considerably depending on the physical effort the work may require. The heat exchange mechanism employs the capacity of human blood vessels to expand from excess heat and contract from cold thereby controlling the blood inflow and outflow in the peripheral blood vessels, and hence the heat flow. The major amount (up to 75%) of heat generated during the performance of light work or at rest at normal air temperatures is exchanged (through the skin) by convection and radiation. High temperatures (higher than 30°C) in a combination with a high degree of humidity (more than 75%) and the work classed as heavy increase heat releases by vaporization of the excess moisture evolving from the body by sweating (hyperhydration). Excessive sweating, however, increases salt losses from the body and lowers blood capacity to retain water.

Fig. 5 shows heat release and hyperhydration related to air temperatures.

Hygienic standards for optimum and safe microclimate. The code of hygienic standards for the design of industrial establishments

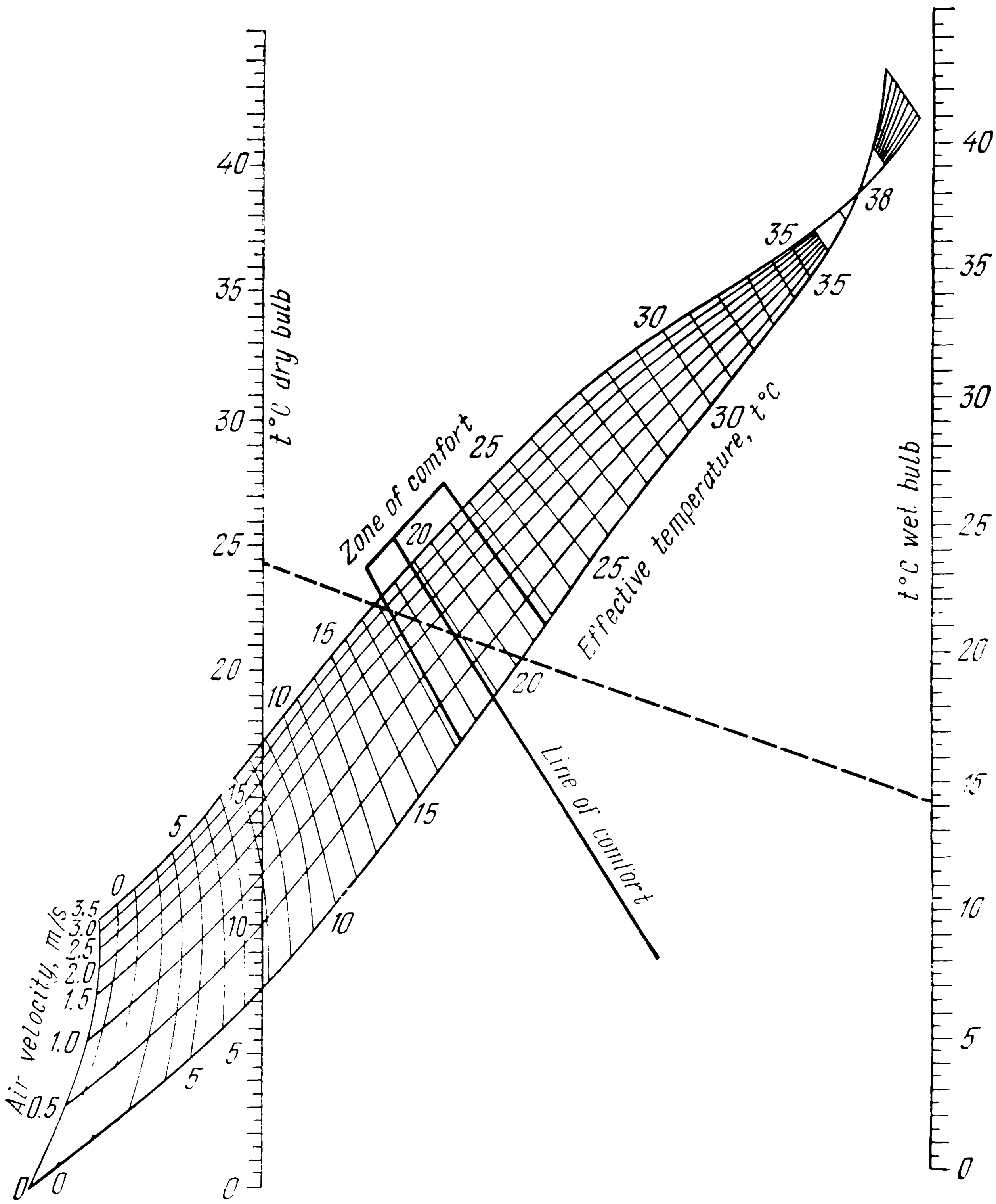

Fig. 4. Nomogram to determine effective temperature and zone of comfort

lays down the optimum and safe limit values for temperature, humidity and velocity of the air about the work zone with allowance made for excess sensible heat, class of work and period of the year. The year seasons are divided between the two periods—the warm period during which the mean daily temperature of outdoor air is

+10°C and higher, and the cold period for which the mean daily temperature of outdoor air is below +10°C.

The optimum microclimatic conditions imply a combination of climatic factors for the working environment which at regular exposure is able to ensure the normal temperature and functioning of the human body without unnecessary heat controlling reactions. These factors are conducive to environmental comfort and a high level of work efficiency.

The safe microclimatic conditions are a combination of climatic factors which at long and regular exposure may cause reversible

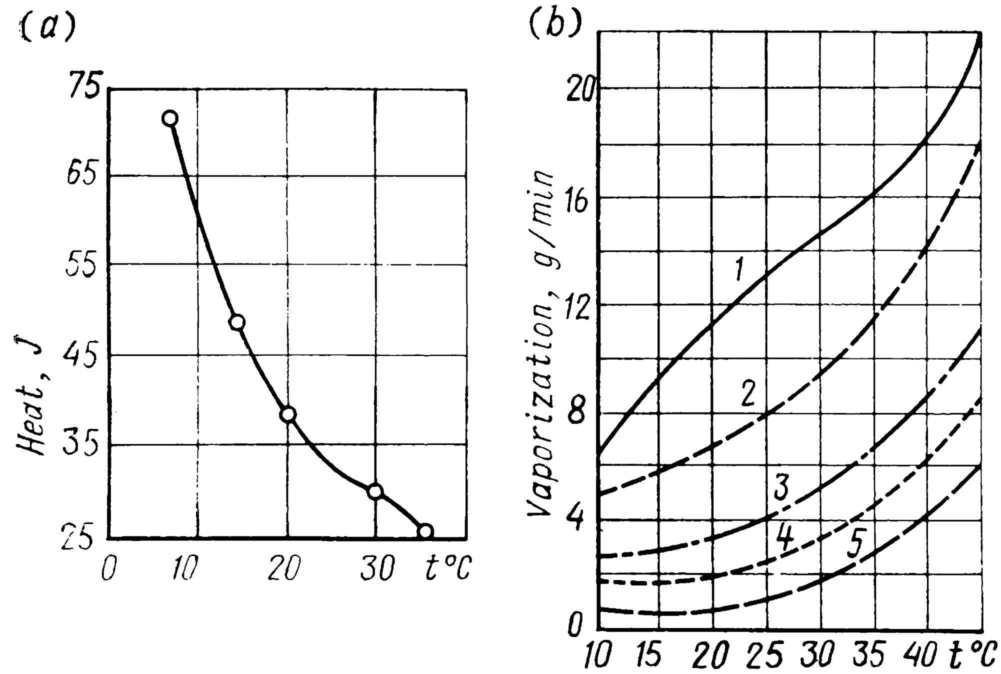

Fig. 5. Heat exchange-temperature dependence

(*a*) heat transfer by radiation; (*b*) heat transfer by vaporization; *1* — very heavy job; *2* — heavy job; *3* — medium job; *4* — light job; *5* — at rest

thermal changes and slight disfunction of the human body the normalization of which may demand a range of heat controlling reactions within the capacity limits of the mechanism of adaptation. Such factors are safe for health although conducive to a slight thermal discomfort, and a lowered efficiency.

The optimum limit values for various climatic factors are given in Table 3; the safe limit values in Table 4 (for the cold period) and Table 5 (for the warm period, in a temperate climate).

To have a better understanding of the material that follows, introducing additional definitions seems to be appropriate.

Available heat is heat coming into workroom from machine-tools equipment, heaters, hot surfaces and materials, occupants, solar radiation, and other sources.

Sensible heat is heat that affects indoor air temperature.

Excess sensible heat is the amount of heat still in surplus in workroom (minus heat losses), at given outdoor air parameters, after

Table 3

Period of year	Class of work	Temperature, °C	Relative humidity, %	Air velocity (max.), m/s
Cold	I (Light)	20-23	60-40	0.2
	IIa (Medium-heavy)	18-20	60-40	0.2
	IIb (Medium-heavy)	17-20	60-40	0.3
	III (Heavy)	16-18	60-40	0.3
Warm	I	22-25	60-40	0.2
	IIa	21-23	60-40	0.3
	IIb	20-22	60-40	0.4
	III	18-21	60-40	0.5

Note. Optimum parameters are ensured by air-conditioning.

all the technological, construction, planning and hygienic countermeasures to reduce surplus heat have been taken.

The amounts of excess sensible heat equalling to and less than 23 $J/(m^3\ s)$ (with allowance for solar radiation) are considered insignificant; those in excess of 23 $J/(m^3\ s)$, significant. Workshops and other premises in which excess sensible heat is significant are classed as "hot-work" shops.

Table 4

Class of work	Temperature, °C	Relative humidity (max.), %	Air velocity (max.), m/s	Temperature outside workplace, °C
I	19-25	75	0.2	15-26
IIa	17-23	75	0.3	13-26
IIb	15-21	75	0.4	13-24
III	13-19	75	0.5	12-19

The standard determining work-zone air parameters permits deviations from the rated values. Thus, relative humidity in workrooms with excess moisture releases may be 10 to 20% higher against the rated values for the warm period, depending on the temperature-humidity ratio, but may not exceed 75%. For jobs classed as light and medium-heavy air temperature should not exceed 28°C, and for heavy jobs, 26°C.

Table 5

Class of work	Temperature, °C		Relative humidity (max.), %	Air velocity*, m/s		Temperature outside workplace, °C	
	with excess sensible heat			with excess sensible heat		with excess sensible heat	
	insignificant	significant		insignificant	significant	insignificant	significant
I	Max. 3° higher than outdoor temperature**, but not higher than 28°	Max. 5° higher than outdoor temperature, but not higher than 28°	At 28°C—55 At 27°C—60	0.2-0.5	0.2-0.5	Max. 3° higher than outdoor temperature	Max. 5° higher than outdoor temperature
IIa			At 26°C—65 At 25°C—70	0.2-0.5	0.3-0.7		
IIb			At 24°C and lower—75	0.3-0.7	0.5-1.0		
III	Max. 3° higher than outdoor temperature, but not higher than 26°	Max. 5° higher than outdoor temperature, but not higher than 26°	At 26°C—65 At 25°C—70 At 24°C and lower—75	0.3-0.7	0.5-1.0		

* Higher velocity conforms to maximum temperature; lower velocity, to minimum temperature.
** Outdoor temperature is the mean daily temperature of the hottest month measured at 1 p.m.

During the cold period, temperatures outside permanent workplaces in heated production quarters and in premises with excess sensible heat and 50 to 100 m^2 of floor area per person are allowed to drop down to 12°C for Class I jobs; 10°C, for Class IIa and IIb jobs; and 8°C, for Class III jobs. But the climatic conditions in workplaces should be maintained as specified by the standard for the cold period.

In the cases where the mean outdoor temperature during the hottest month at 1 p.m. exceeds 25°C (23°C for heavy jobs), indoor temperature at workplaces may, with relative humidity being constant, be 3° higher (but not higher than 31°C) for workrooms in which excess sensible heat is insignificant: and 5° higher (but not higher than 33°C) for workrooms in which excess sensible heat is significant.

For all jobs classed as heavy, the above tolerances for safe air temperatures are 2° less.

In permanent workplaces meant for jobs under Classes IIa and b, and III, also where heating and ventilation systems employ forced-type air supply, the air velocities may be increased up to 0.7 m/s with a concurrent air temperature rise of 2°C.

The standard safe limit values for microclimatic factors in the work zone of production quarters make allowance for excess sensible heat. Microclimate within enclosed areas depends on the climatic factors of outdoor atmosphere which should be taken into account in the design of industrial buildings, choice of construction material, type of fuel, heating and ventilation systems. More important, however, is excess heat which is often due to radiation from high-temperature or molten metal, naked flame, hot surfaces of machine and equipment, heaters, etc. Much heat is produced by solar radiation coming through windows. All sources of radiant heat (besides a direct effect on the workers) heat up construction elements of industrial buildings—walls, floors, etc. As a result, the air temperature rises above normal which brings about discomfort for the workers.

The sanitary standards delimit the effect of radiant heat at permanent workplaces to 1.25 MJ/(m^2 h); with higher rates of radiation provision should be made for air douche. Air velocities for such air douches are given in Tables 3, 4 and 5.

Radiant heat is conducive to uncomfortable microclimate about the workplace and is considered as an industrial hazard. As a source of radiant heat metal, molten or heated to high temperatures, presents serious danger to health and may lead to accidents. As was mentioned earlier, heat transfer occurs basically by convection, conduction and radiation. Intense infrared radiation does not heat the air but when absorbed by solid bodies in which radiant energy converts to heat energy these solid bodies become sources of heat

and in their turn heat the air by convection. Infrared radiation affects not only the skin surface but also causes biochemical changes in the blood system and may seriously affect the cardiovascular and nervous systems of the human-being. Long exposures to infrared radiation leads to lenticular opacity or radiation cataract.

Both radiant heat and direct contact with molten or high-temperature metal are conducive to injuries, such as skin burns.

By depth of lesion, burns are usually classified into four degrees:

degree I burns cause skin reddening and edema; they heal in 4-5 days;

degree II burns show blisters on the reddened skin surface.

The blisters are filled with transluscent yellow fluid. They are not allowed to be pinholed but if it occurs, the blisters expose bright red sore surface of the skin growing layer. Unless infected, such burns heal up in 10-15 days and leave no scar on the skin surface;

degree III burns are usually followed by skin necrosis with the formation of crust, grey or black in color; and

degree IV burns are followed by skin necrosis and even charring of not only the skin but also of the underlying tissue (muscles, tendons and bones). The dead tissues which may partially be melt down are usually rejected in a few weeks. Healing is a slow process and results in scars and various kinds of contracture.

By cause, burns are classified as thermal, chemical, radiation, and electrical. The severity of burns depends not only on the degree of lesion but also on the area of the affected region in percent to the total skin area of the victim. If the affected area is large the injury results in the general disfunction of the body and even in shocks, if the area is not less than 30% of the body total skin surface. With degree II-IV burns there is danger of toxemia to be followed by the burn toxicosis, and even sepsis.

In the cases of thermal burns the first-aid recommendations include the immediate stoppage of action of high temperature, dressing degree I burns with 70% alcohol solutions or perfume which measure for degree II burns should be followed by a dry sterilized, or 10% potassium permanganate impregnated, gauze bandage. The first-aid for chemical burns requires immediate rinsing of the affected skin region with weak solutions of soda (acid burns), and vinegar (alkali burns), or pure water to be followed by a dry sterilized gauze bandage. Radiation and electrical burns usually demand for special medical attention.

Overheating and its prevention. Protective measures against radiant heat and effect of high temperatures include the insulation of hot surfaces, shielding of heat radiation sources, control of heat supply into work areas and its effect on the occupants, use of air douche, personal protective equipment, provision for potable water, and rational organization of work and rest.

Heat insulation is an effective means against intense heat radiated from hot surfaces. It prevents direct contact with danger spots and thus protects against possible burn injuries. Insulation limits the temperature of equipment surfaces (furnaces, baths, etc.) and machine guard members to 45°C, as is prescribed by the sanitary standard. Heated surfaces are insulated with materials whose heat conduction is poor. This brings down the temperature of external surfaces that radiate heat and reduce heat transfer by convection.

Furnaces, heat cabinets and other heat installations subject to maintenance and repairs should be cooled down to 40°C before these works begin. During repair and maintenance operations, the workers inside heating units are blown with fresh humidified air supplied to the workplaces via rubberized air lines from portable air conditioners. Continuous supply of potable water is essential for normal functioning of the human body when exposed to hot environment of heat-treating departments. On exposure to heat, the human body loses up to 10-12 liters of water and 50-80 g of salts by sweating and vaporization. Replacement of both is very essential and can best be achieved by drinking carbonized water with 0.5% addition of table salt. Water stands are usually located in close vicinity of workplaces and are rated for a consumption of 4-5 l of water per person per shift. The temperature of potable water can be varied from 8 to 20°C.

Beside water supply, the sanitary-hygienic regulations envisage the provision of regular breaks and specialized places for rest during work interruptions. A 10-15 min break gives relief to the body and brings heat control reactions back to normal. During such breaks the workers rest in specially furnished and environmentally controlled places (rooms) separated from the work zone. Velocities of the conditioned air flows in such places can be varied, depending on the ambient temperature, from 0.5 to 3.0 m/s.

Overcooling and its prevention. Low temperatures exert unfavorable influence on the human body and aggravate the physical state of the worker, and as such are also referred to industrial hazards.

The minimum temperature permissible by sanitary standards in production areas (for heavy jobs) is 13°C. Air temperatures below this limit are considered uncomparable to the standard working environment. Work at low temperatures may be associated with low-temperature treatment of tools and workpieces; with erection, maintenance during the cold period of equipment positioned for technical and safety reasons in the open; with instances of emergency control and maintenance of power lines, water supply, sewage and steam pipelines, ventilation and heating systems; with operations at storage grounds, etc.

At low temperatures the body heat generation might be not enough

to compensate heat losses and the body temperature can go down below normal. At a body temperature below 34°C there comes weakness, flabbiness, sleepiness and lowered fitness to work. As a result of low temperature exposure some peripheral organs to which blood supply is difficult, may get overcooled and even frost-bitten. The human body responds to lower temperatures by reducing heat transfer from the skin surface. Blood vessels contract, the rate of blood flow slows down, and hence the heat exchange through the skin by conduction and radiation is reduced.

The danger of frostbite for those working outdoors at low temperatures (and particularly in the wind) is really great as the cold exerts a slow and painless influence upon a man and can pass unnoticed during the working process.

First-aid recommendations differ depending on the severity of frostbite. By depth of lesion, frostbites are classed into:

stage I frostbite or light frostbite which after warming up shows a rapidly developing edema on the frostbitten region which turn cyanitic;

stage II frostbite showing blisters filled with hydropic fluid;

stage III frostbite which exhibits skin blisters filled with a blood-tinged fluid; in a few days the blisters are replaced by necrotic regions which are soon rejected leaving scars over the skin surface; and

stage IV (deep) frostbite, affects not only the skin but also the underlying soft tissues and even bones. The dead tissues dry out, get shrunk, turn dark-brown and are slowly rejected. Healing takes several weeks and even months. The severity of frostbite injury depends on the length of exposure.

The first-aid includes taking the victim indoors to warm him up as soon as possible with hot-water bottles (the water should not be very hot to avoid burning of the affected, insensitive regions), and hospitalization. Frostbitten areas may be dipped into warm water and rubbed until the skin reddens and recovers sensitivity, and dressed up with gauze bandage. To avoid further supercooling and infection one shall not use snow or cold water for rubbing and warming purposes.

Preventive measures against overcooling and frostbite include the introduction of regular breaks during the work and provision of warm clothes for the workers.

One other hazard from low temperatures is cold infirmity caused by long exposure to draughts, which are characterized by sharp fluctuations of temperature, aggravated by high airflow velocities. To avoid draughts, the gates, doors, other large openings and passages should have inbuilt vestibules, or use heated air curtains.

2.3. PRINCIPLES OF SANITATION AND INDUSTRIAL HYGIENE

Sanitary regulations lay down the general safety requirements for manufacturing processes and industrial equipment that should be designed so as to avoid, or at least minimize, releases into the air of production quarters, outdoor atmosphere and industrial wastes, of dangerous and odorous substances, excess heat and moisture, and dusts.

The practical safety measures to meet such requirements include the replacement of harmful substances by the inert or less harmful; dry methods for processing pulverized materials by wet processes; naked flame heating by electrical heating; solid and liquid fuel by gaseous kinds of fuels. Safety of industrial installations and equipment can also be achieved by ensuring airtight joints and sealings; thermal insulation for hot surfaces of equipment, machines, airducts and pipelines; tight closures for load capacities in mechanical handling of loose materials; using hydraulic or pneumatic methods for handling pulverized materials.

Dust control should begin at the stage of designing industrial buildings, equipment, machine- and handtools so that they would ensure dust-free manufacturing processes. Bringing dust concentrations to safe levels can be achieved by various methods.

Departments dealing with pulverized materials or dusty processes must be located separately from other workshops. As far as practicable, the floors should be made smooth and the walls painted with oil-based paints to prevent dust absorption by their surfaces. Humidification is another effective means of controlling dust content in the air. It is advisable that all the processes associated with dust releases be automated or controlled remotely, from safe places separated, or otherwise protected from dust penetration.

Provision for hourly air changes by ventilation is one of the essential measures to optimize microclimatic parameters and contents of the air.

General ventilation should be designed so as to exclude the possibility of air exchange between the "dusty" and "clean" work areas. The hygienic standard establishes that the space per person within industrial buildings should be not less than 15 m^3, and the floor area, 4.5 m^2. In the production quarters where space per worker is up to 20 m^3 and the air is free of industrial contaminants, ventilation should be rated for not less than 30 m^3/h of fresh air per worker; and where space is 20 m^3 and more, 20 m^3/h per worker. In less crowded work areas where each worker enjoys 40 m^3 of space and more, air changes can be achieved by periodic opening of the windows and ventilation lanterns. In all cases, however, the temperature, humidity in the work areas should be controlled or adjusted accordingly.

To make a good choice of a ventilation system for production quarters where releases of excess heat, moisture, harmful substances, vapors, gases and dusts are unavoidable it is necessary to calculate the volume flow rate of fresh air which for the cold and warm periods is different. Unless the calculation should be based on the actual value of air density, the value γ is normally assumed equal to 1.2 kg/m^3.

Volume flow rate calculations can be made using the following formulas:

for air flow rates based on excess sensible heat,

$$L_1 = L_{w.z.exh} + \frac{Q_{sens} - 0.29 L_{w.z.exh} (t_{w.z.exh} - t_{sup})}{0.29 (t_{non\ w.z.exh} - t_{sup})}$$

where $L_{w.z.exh}$ is the amount of air removed from work zone by local exhaust and general ventilation, or bled off for process or other needs, m^3/h; Q_{sens} is the excess sensible heat, J; $t_{w.z.exh}$ is the temperature of air removed from work zone by local exhaust and general ventilation, or bled off for process or other needs, °C; $t_{non\ w.z.exh}$ is the temperature of air removed from outside work zone, °C; t_{sup} is the temperature of supplied air, °C;

for air flow rates based on excess moisture,

$$L_2 = L_{w.z.exh} + \frac{W - 1.2 L_{w.z.exh} (d_{w.z.exh} - d_{sup})}{1.2 (d_{non\ w.z.exh} - d_{sup})}$$

where W is the rate of excess moisture releases, g/h; $d_{w.z.exh}$ is the moisture content in air removed from work zone by local exhaust and general ventilation, or bled off for process or other needs, g/kg; d_{sup} is the moisture content in supplied air, g/kg; $d_{non\ w.z.exh}$ is the moisture content in air removed from outside work zone, g/kg;

for air flow rates based on excess available heat,

$$L_3 = L_{w.z.exh} + \frac{Q_{avail} - 1.2 L_{w.z.exh} (I_{w.z.exh} - I_{sup})}{1.2 (I_{non\ w.z.exh} - I_{sup})}$$

where Q_{avail} is the amount of available heat, J; $I_{w.z.exh}$ is the heat content in air removed from work zone by local exhaust and general ventilation, or bled off for process or other needs, J/kg; $I_{non\ w.z.exh}$ is the heat content in air removed from outside work zone, J/kg; I_{sup} is the heat content in supplied air, J/kg;

for air flow rate based on the rate of release of harmful substances

$$L_4 = L_{w.z.exh} + \frac{Z - L_{w.z.exh} (z_{w.z.exh} - z_{sup})}{z_{non\ w.z.exh} - z_{sup}}$$

where Z is the rate of release of harmful substances into the air, mg/h; $z_{w.z.exh}$ is the concentration of harmful substances in air removed from work zone by local exhaust and general ventilation, or bled off for process and other needs, mg/m^3; $z_{non\ w.z.exh}$ is the

concentration of harmful substances in air removed from outside the work zone, mg/m^3; z_{sup} is the concentration of harmful substances in supplied air, mg/m^3.

In cases of simultaneous releases into the working atmosphere of heat, moisture and harmful elements, air-exchange rates are calculated using all the above formulas separately for the cold and warm periods, and the choice is made for the largest value.

The calculated in this way volume flow rates of fresh air should not be less than the necessary minimum (see page 46). Where there is risk of flammable vapors or toxic gas concentrations in the air, the calculations for the necessary volume flow rate of fresh air should be checked to see that the content of such harmful elements does not exceed 5% of their minimum safe limits to avoid ignition.

In accordance with the code of practice for the construction of industrial buildings, temperature, content of moisture and heat of the air coming into the inlets of local exhaust and general ventilation, and at bleed-off points located in the work zone are assumed as follows:

$$t_{w.z.exh} = t_r;\ d_{w.z.exh} = d_r;\ I_{w.z.exh} = I_r;\ \text{and}\ z_{w.z.exh} = \text{MSC}$$

where t_r, d_r and I_r are the standard rated values for temperature, moisture and heat content in the air of work zone; and MSC is the max. safe concentration of harmful elements in the air of work zone, mg/m^3.

The air changes per hour, i.e. frequency of air volumes replaceable during each hour of work, can be obtained from

$$K = L/V,$$

where K is the number of air changes per hour; L is the volume of air removed per hour, m^3; V is the internal free space of the area being ventilated, m^3.

Where the ventilation is of the general type, i.e. effected by dilution, determining the necessary volume flows of fresh air by the calculation of the air changes only is unadvisable.

2.4. VENTILATION SYSTEMS

The normal microclimate in production areas depends very much on the proper choice of a ventilation system. Ventilation, whether general ventilation or local exhaust ventilation, falls within the province of industrial hygiene as it is primarily intended for diluting to safe limits or altogether removing explosive dusts, flammable vapors and corrosive gases from the working atmosphere. Ventilation systems however require careful designing. This applies particularly to exhaust ventilation which, if badly designed, can be worse than no ventilation at all. Exhaust hoods or slots should be so located

that no part of the fumes or dusts being removed can enter the worker's breathing zone. At the same time, ventilation should ensure that other conditions (equipment, structural elements of buildings, etc.) satisfy the requirements of the manufacturing process. Ventilation in industrial buildings and other auxiliary facilities is mandatory.

Ventilation is the process of replacement of vitiated air by fresh air.

Depending on how the air currents are induced, ventilation can be *natural* or draught and *mechanical*. A combination of the two types is known as the *compound* ventilation.

Mechanical ventilation, depending on the direction of induced currents, can be exhaust, forced (plenum), and plenum-exhaust.

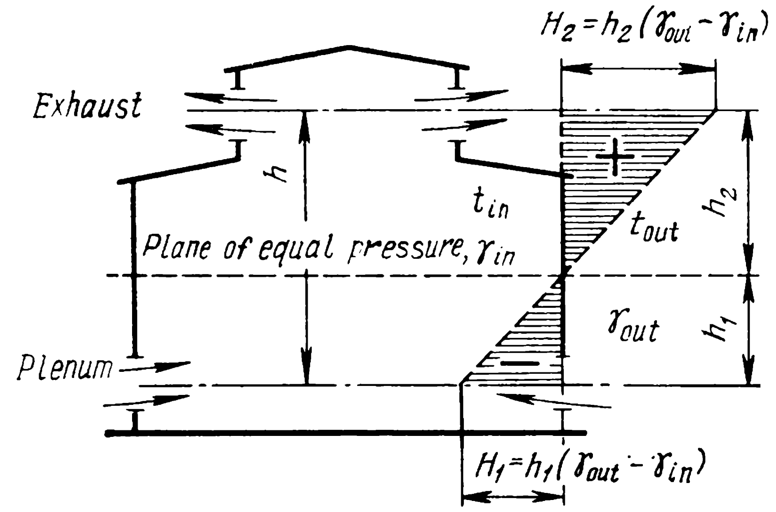

Fig. 6. Distribution of air pressure in a naturally ventilated enclosure

By scope of action, distinction is made between the *general* (dilution) and the *local* ventilation. The two types can be used in combination.

By status, ventilation falls into the *operating* or normal and *emergency* ventilation.

Proper choice of a ventilation system is essential for ensuring continuous supplies of good quality air into production areas. Ventilation should be effective, reliable and least expensive in regard to the cost of construction and operation.

Exhaust ventilation, for example, is one means of removing explosive dusts, flammable vapors and corrosive gases. Determining proper places of their possible releases and providing such hazardous spots with exhaust inlets and return points is very essential from the safety standpoint. It should however be noted that the provision of exhaust ventilation only is a limited measure and should be considered as supplementary to the general ventilation by dilution.

Natural ventilation, unless induced artificially, occurs through untight closures in doors, windows and various other openings by effect of temperature and difference of specific weight of the indoor (t_{in}, γ_{in}) and outdoor (t_{out}, γ_{out}) air, velocity and direction of wind. Fig. 6 shows schematically the distribution of air pressure and the

difference in the elevation of the inlet and outlet openings provided for natural ventilation. The use of natural ventilation requires that the equipment be positioned at right angles to the longer walls to ensure free passage of air currents.

Machine-tools and other equipment pieces should be spaced no less than 2 m apart one from another. At each spacing, air inlets in the form of windows or fanlights are provided in the longer walls to let in free air flows, when opened. The fresh air is thus supposed to replace rather than mix up with the vitiated air.

The various types of natural ventilation are the airing and aeration.

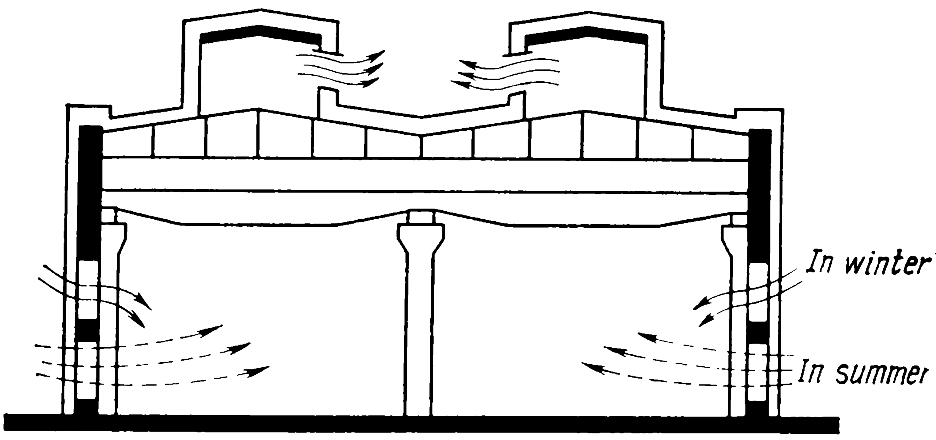

Fig. 7. Aeration during the warm and cold periods: in- and outflows of air

Airing is achieved by periodic opening of air wings and fanlights in the windows and lanterns, respectively. During the cold period a minimum of air changes per hour is allowed in workrooms. It is essential that airing will induce no changes in the temperature of the air in workrooms against the rated, nor be conducive to the formation of mists, condensation of water vapors on the wall, floor or glass-fronted surfaces.

Aeration is the induced natural ventilation that serves the purpose of general (dilution) ventilation for industrial building interior space to maintain the necessary air quality within the specified limits (Fig. 7).

Aeration can be effective with the proper physical positioning of the industrial buildings, i.e. at right angles or at least at 45° to the direction of the prevailing wind. It is desirable that air vents, window wings or leaves in roof lanterns are so designed as to be easily controlled from the floor level. Air currents are induced by adjusting the above vents with due regard to the force and direction of the wind (Fig. 8).

Aeration is effective only if the mechanical control mechanisms for frequent shutting and opening of the window wings and lantern leaves are well designed and dependable. Where the number of fan-

lights and air vents are large, opening and shutting can be controlled by a mechanical drive-mechanism.

The choice of the length-width ratio for fanlights, the position of their axis of turning and the angle of opening are very essential for effecting air exchange by aeration. To achieve good air exchange, fresh air inlets are provided at a height of no more than 1.8 m above the floor level in the warm period, and not less than 4 m above the floor in the cold period to prevent direct currents of cold air on the workers and avoid incidence of cold or chill infirmities. For this

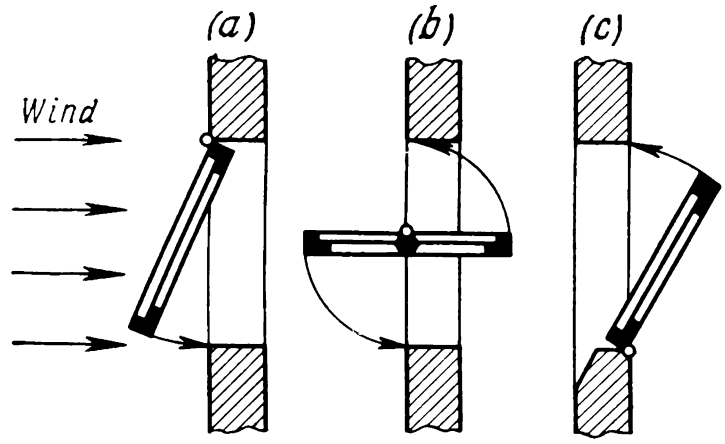

Fig 8. Types of window casement

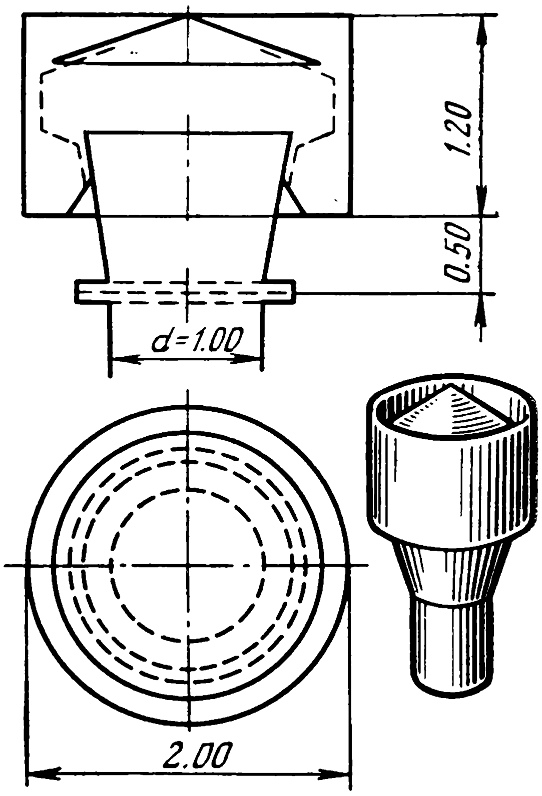

Fig. 9. A deflector

purpose, two rows of fanlights are made on the longer walls of industrial buildings. In the work areas where air changes cannot be effected too often, use is made of exhaust ducts or shafts the uppermost portion of which is led above the roof ridge. To increase efficiency of air exchange the exhaust air ducts are crowned with diffusor attachments or deflectors.

Deflectors increase the draught of the indoor warm air due to wind force. There exists a large number of deflector types of various design. A schematic design of the commonest type deflector is shown in Fig. 9. The deflector is a branch pipe that flares at the top to form a diffusor which is capped with a baffle secured to the branch pipe upper portion. Both the diffusor and baffle are housed in a cylindrical shell which through arms is fixed to the diffusor so that certain space separates them. The deflector is installed over the top of an exhaust duct or shaft to catch wind. By wind action, air currents flowing about the shell outer surface build up a vacuum in the diffu-

sor thereby increasing the exhaust flow from the enclosure. Because deflectors are usually mounted over the roof ridge of industrial buildings and shaped circular they catch any slight wind from any direction. The design prevents inverse draft in the enclosure and protects the shaft from the atmospheric precipitation.

The advantages of natural ventilation include simplicity of design, low cost of operation and maintenance, possibility of ventilating large production areas with excessive releases of heat and air contaminants. For example, about 40 air changes per hour can be achieved by aeration at an autoworks forge shop during the summer with volume flow rates of about 3 000 000 m^3 per hour. To achieve this by means of mechanical ventilation would have required complicated equipment, much power and skilled personnel.

Natural ventilation however has its demerits. Thus, it does not provide for heating, cleaning, humidifying and delivering of the air to certain workplaces as may be required.

Although it involves much capital input and operating costs, mechanical ventilation technically is superior to natural ventilation. It provides for drawing of the air from where it is clean; if necessary, for conditioning—heating, washing or drying, and for purifying the air, and delivering it to any place within a production area as may be required.

Mechanical ventilation can be of different types, namely the forced (plenum), exhaust, and plenum-exhaust ventilation (Fig. 10).

Forced ventilation (Fig. 10*a*) is a system whose function is to force fresh air through ventilation ducts to workrooms with excess heat and minor concentrations of harmful elements in the air. The removal of foul air through fanlights and ventilation shafts is not only due to heat load and wind force but also due to the effect of overpressure created by forced ventilation. Fresh air is distributed between various sectors of a production area through a network of airducts passing to workplaces where it emerges from various inlet grills and other outlets (Fig. 11).

Exhaust ventilation (Fig. 10*b*) can be used in enclosures free of releases into the air of harmful substances, also in workrooms where few air changes are sufficient, in auxiliary-type structures, service rooms and warehouses. In such cases, fresh air is supplied by natural ventilation through air vents and windows, through voids in the walls and floors, also through untight closures at doors, windows, and from adjacent rooms. This last is not objectionable unless the air in the neighboring area contains harmful substances.

Plenum-exhaust ventilation is necessary in all production areas where the nature of production demands for an exceptionally dependable air exchange. When using this type of ventilation it is desirable to build up a little overpressure within workrooms where the atmosphere is relatively free of or contains but negligible amounts of

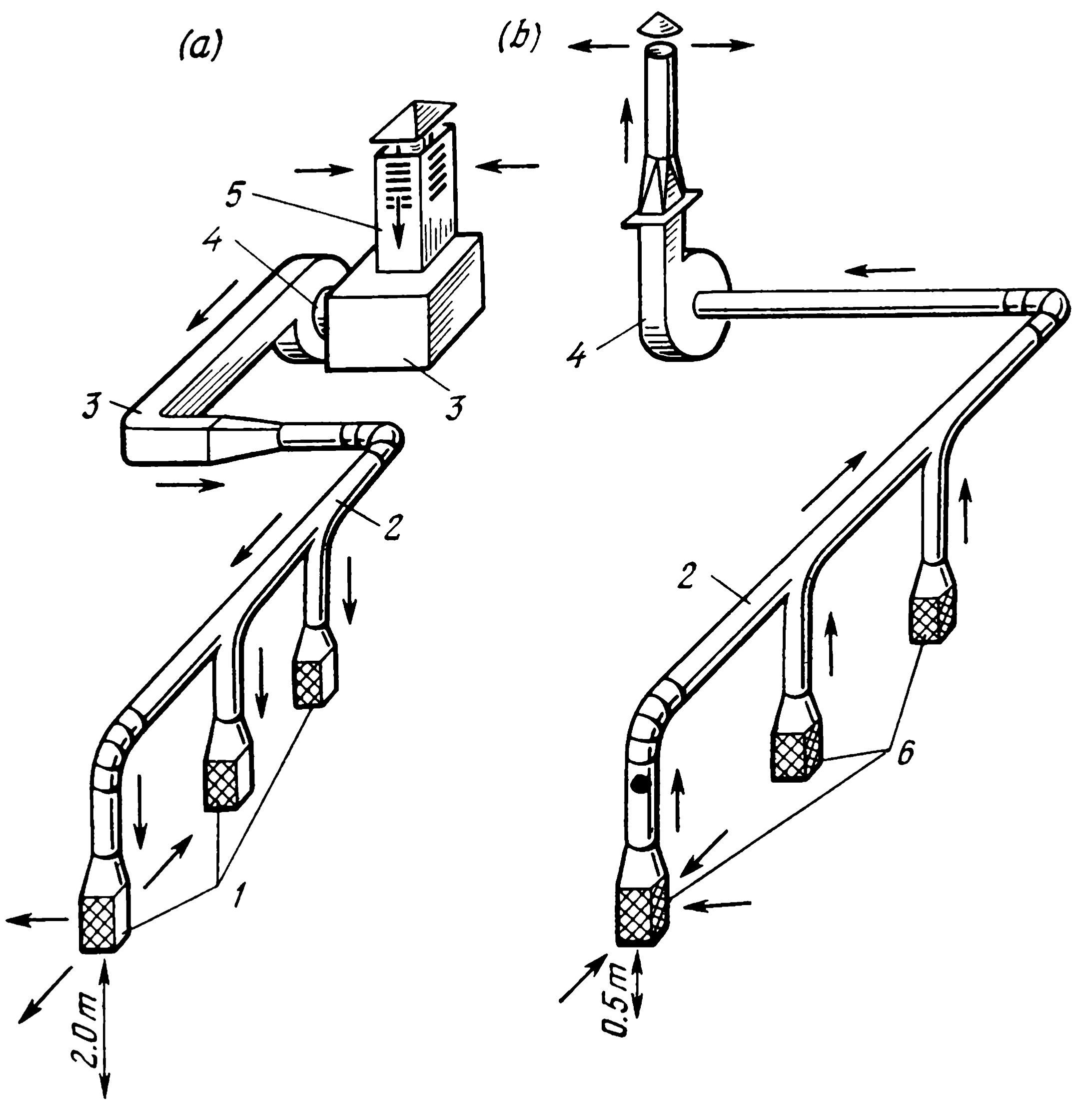

Fig. 10. Mechanical general ventilation systems
(*a*) forced; (*b*) exhaust; *1* — plenum air outlets; *2* — air ducts; *3* — air heater; *4* — fan; *5* — plenum (intake) shaft; *6* — exhaust air inlets

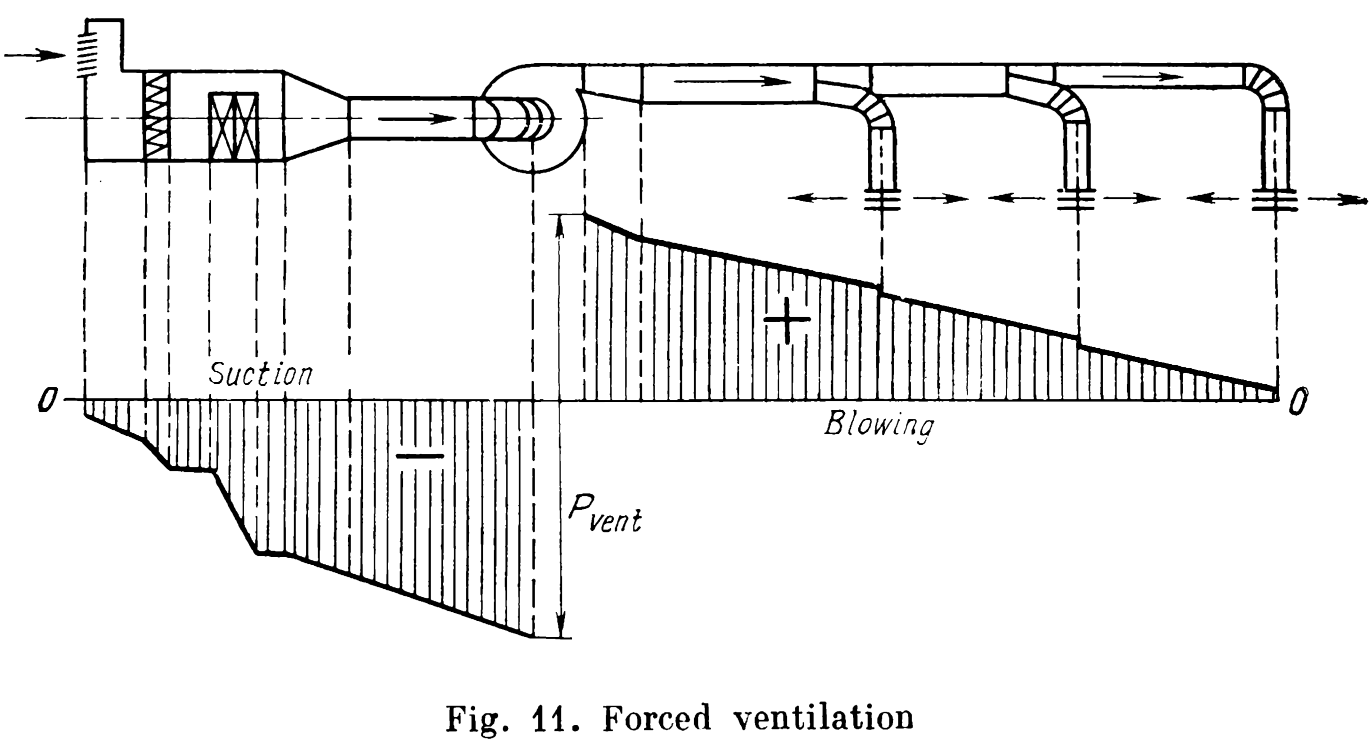

Fig. 11. Forced ventilation

airborne comtaminants to prevent the spread of vitiated air from the neighboring quarters where harmful releases may be quite significant. Fresh air outlets should be made so as to face the front line of machinery or other industrial equipment pieces. Exhaust scoops and slots should be positioned at any suitable level to catch unclean air currents that normally tend to follow the direction of natural air draft. The most suitable places to install exhaust uptakes would thus be the lower quarters of workrooms where dusts, vapors and gases heavier than the air tend to accumulate more intensively.

To save the cost of air heating during the cold period the plenum-exhaust type of ventilation can use partly the return air which must

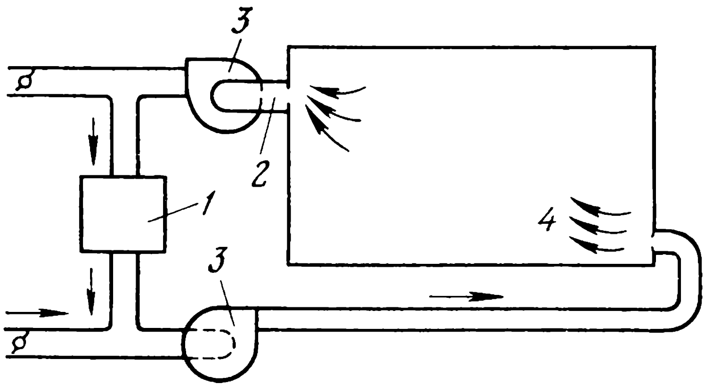

Fig. 12. Schematic air exchange in an enclosure by recirculation
1 — air cleaner; *2* — exhaust duct; *3* — fans; *4* — ventilated enclosure

be precleaned and, if necessary, conditioned prior to recirculation. It is mandatory to mix recirculated air with fresh (outdoor) air whose proportion in the total amount of the air supplied to the enclosure should constitute no less than 10%. The content of harmful elements in such air should constitute not more than 30% of their maximum safe concentration. A schematic air exchange by recirculation in an enclosure is shown in Fig. 12. The use of return air is not permitted in production areas where the working atmosphere contains harmful elements under the hazardous Classes 1, 2 and 3, also odorous substances and pathogenic microorganisms, and where there is risk of sudden outburst into the air of large quantities of explosive dusts and flammable vapors and gases.

Compound ventilation, the combination of mechanical and natural ventilations, can be resorted to where mechanical ventilation may unobjectionably be supplemented with natural ventilation for delivering or exhausting the air.

Local ventilation may be of the exhaust and the plenum type. Local exhaust ventilation is intended for the removal of specific air contaminants directly from where they form or release to prevent their spread throughout the atmosphere of the production area, or to minimize harmful releases into the air in workrooms or production

sectors, enclosures, etc. The advantage of local ventilation lies in that it prevents pollution of the entire air space within a working enclosure and exhausts minimum air volumes containing concentrated amounts of dangerous impurities.

Local exhaust is a variety of local ventilation intended to remove all kinds of health and safety hazards, such as excess heat, moisture, gases, vapors and dusts. By purpose and design, local exhausts are

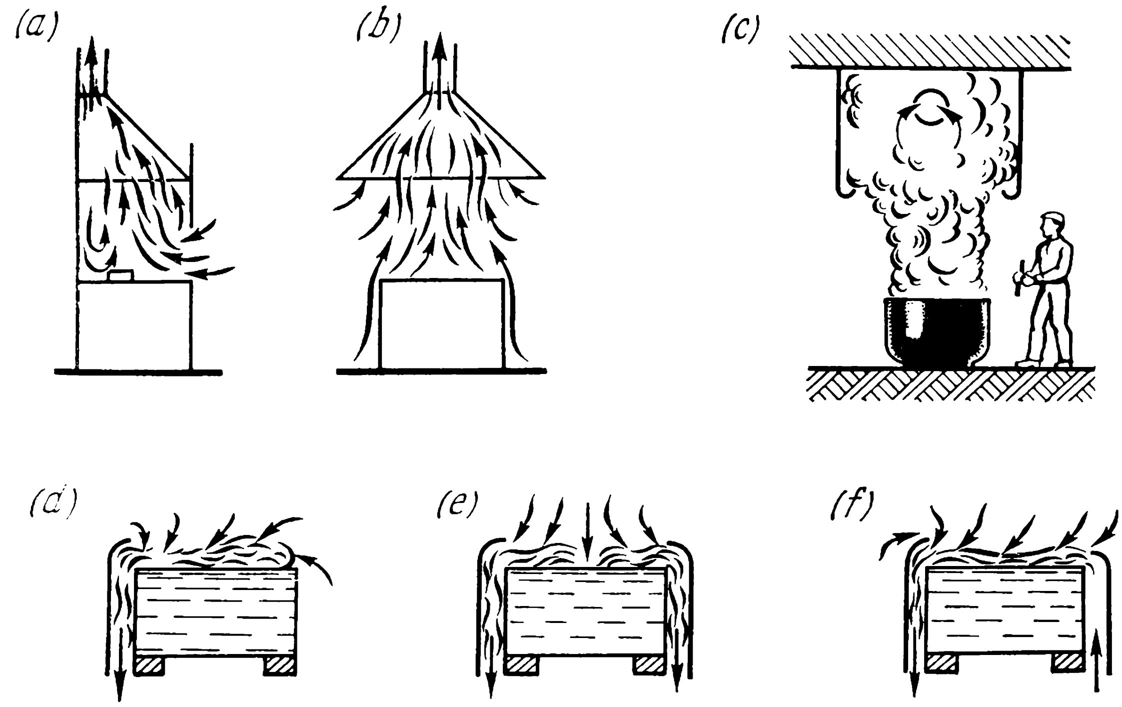

Fig. 13. Types of local exhaust
(*a*) exhaust cupboard; (*b*) exhaust hood; (*c*) platen; (*d*) unilateral slot exhaust; (*e*) bilateral slot exhaust; (*f*) over-blowing

distinguished into exhaust cupboards, exhaust side slots, dust aspirators or dust evacuators, and exhaust hoods (Fig. 13).

Exhaust cupboard provides a complete enclosure of a process or source of harmful releases. The process or operation inside the cupboard is controlled remotedly or manipulated mechanically from a safe distance through an access door provided for this purpose. Outbursts of dust or gases into the workroom through the access door and various other leaky points of the exhaust cupboard are avoided as the rate of air suction into the cupboard through the above mentioned openings is several times that of gas diffusion or dust-particle dispersion in the air. The air discharges are insignificant as the suction is limited to the small areas of access door and leaky points.

Various-purpose drying chambers, paint-spray booths, other commercial-type chambers widely used in manufacturing industries can serve as examples of local exhausts of this type.

Rate of discharge L (m^3/h) through local exhaust can be determined from the formula

$$L = Fv\,3\,600$$

where F is the area of exhaust uptake, m^2; v is the rate of air suction, m/s.

The air velocities at exhaust entries or slits in workrooms (where processes involve no heating or harmful releases induced by mechanical agitation and where airborne contaminants can be classed as near- or non-toxic) normally range between 0.5 and 0.7 m/s. The velocities are increased to 1.0-1.5 m/s for workrooms in which the atmosphere contains toxic substances with MSC < 0.1 mg/m^3, also where heat is excessive or there is a risk of sudden outburst

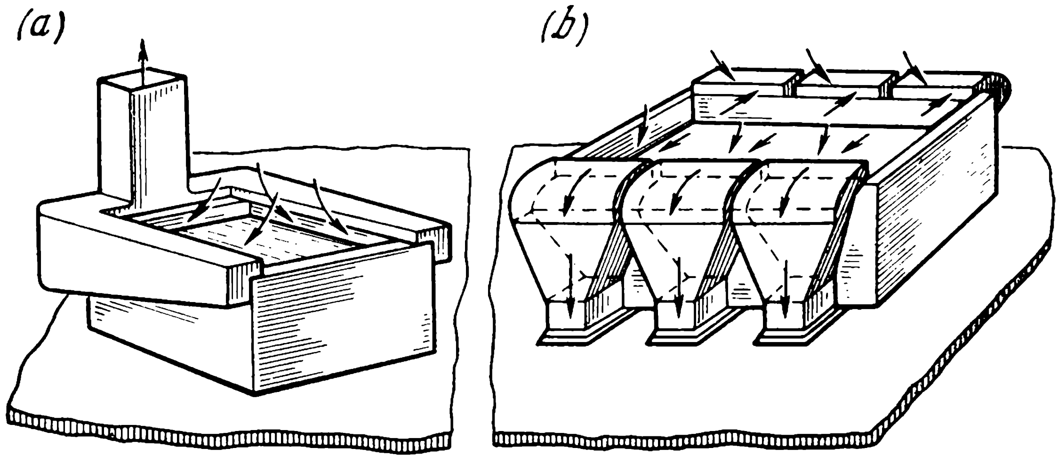

Fig. 14. Side slot exhaust
(*a*) continuous; (*b*) in sections

into the air of large quantities of harmful elements. Where several hazardous factors are present in a combination, the velocities at the air exhaust uptakes can be increased to 5 m/s.

The necessary velocity of the air sucted into small-section exhaust holes can be achieved by building a vacuum in the exhaust airway of up to 100 Pa against the environment pressure.

Exhaust side slots are provided for manufacturing processes taking place in the industrial-type baths that use various kinds of process solutions. These exhausts can be unilateral and bilateral.

Unilateral side-slot exhausts are provided at either side, and bilateral at the opposite sides of bath receptacles. The last exhausts can operate by way of cross-blowing. A narrow airstream is forced from one side through 5-7-mm wide slot outlet at a velocity of 6-10 m/s over the evaporating surface and drawn at the opposite side of the bath. Exhaust side entries can be made continuous and in sections (Fig. 14). This type of exhaust is ineffective where both processes involve high temperatures and use highly volatile process solutions because the internally-induced convective currents may change the direction of cross-blowing thereby preventing proper evacuation of harmful substances by the exhaust system.

Dust aspirators are exhaust scoops whose function is to remove dust immediately as it is formed in large quantities due to the neces-

sity stipulated by the manufacturing process, and to protect the working environment from contamination and the worker from accidents. Local exhausts of this type are usually provided at tool-grinding machines.

Exhaust hoods, positioned at a certain height or distance from spots that present health hazards, are designed so as to allow the operator free access to the equipment or process he operates. Increased distance between the source and the hood increases the air ingress

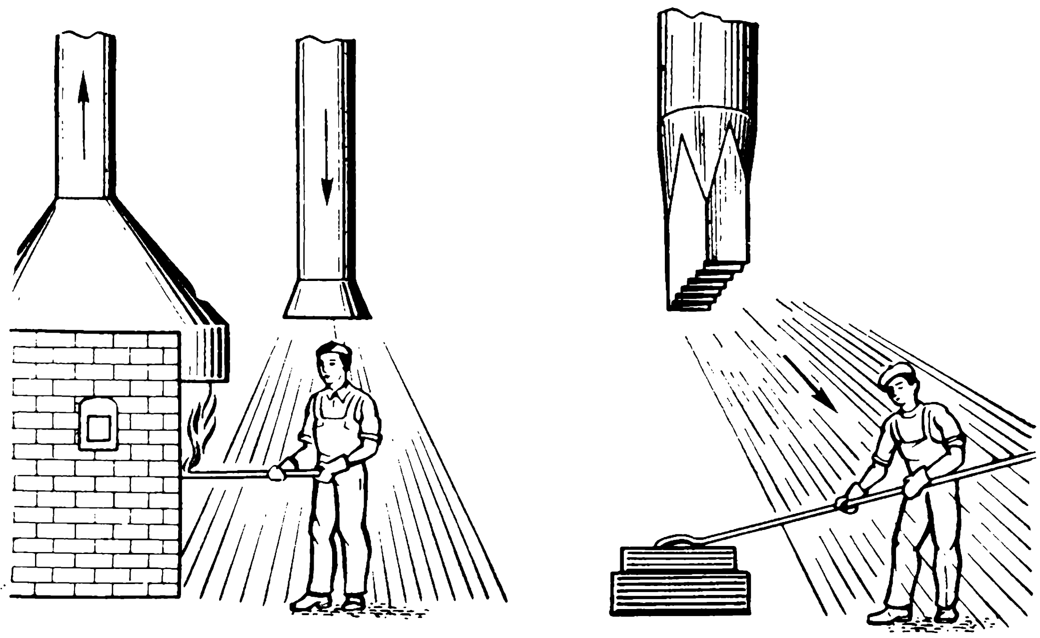

Fig. 15. Air douche at workplace

from the workroom. Because the air suction rate is inversely proportional to the squared distance, there is always a risk that currents of foul air may miss the hood entry.

Usually, the exhaust hoods are effective when harmful substances are lighter than the air. Exhaust hoods can use either natural or induced draft. It is normally accepted that the vitiated air enters across the hood open section at a velocity of 0.8-1.2 m/s.

Air douche is a device in a system of local forced ventilation that improves air conditions to an optimum of human comfort by blowing controlled airstreams at the person in workplace. The air within the zone it covers is usually cooler as compared to the rest of the premises (Fig. 15). Air douche units can be stationary and portable. Stationary systems draw fresh air, pre-heat it to 16-24°C, and deliver it to particular points in the work zone at 0.5-3 m/s, as specified by the design. Portable air douche units use the room air cleaned by way of filters from dust prior to admission to workplaces. Effective means of improving the working environment, air douche is widely used in manufacturing industries—at casting platforms and charge floors in foundries, at forge hearths and furnaces in forge and heat-treating departments.

Because air douche does not reduce concentration of noxious gases, vapors or dusts in whole of the production area, it is therefore practicable to use it in a combination with a system of general ventilation.

Air curtain is a device for preventing the entry of cold outdoor air into an industrial space and for restricting the zone, or avoiding spread, of harmful releases about the production area or enclosure. Air curtains are often used in assembling departments of plants and factories, for example, to cut off paint-spray sectors from the rest of the enclosure to prevent spread in the department's atmosphere of noxious substances, flammable vapors, atomized paint droplets and other like contaminants. Such a barrier is achieved by placing air ducts along the sector's perimeter upper portion with linear slot through which the air is delivered by a fan with a high velocity to pierce vertically the space down and enter the exhaust grilles provided along the sector's perimeter lower portion. In this way, the spread of harmful substances is prevented or limited as they are entrained by the high-velocity air jet down the subsurface exhaust works. The air supplied by the fan is often preheated; this type of unit (when used with an air preheater) is called the heated-air curtain.

It is customary to install curtains of fresh or heated air at factory gates which have to be opened more than 5 times, or remain open for no less than 40 min, during an 8-hour interval, at the so-called technological openings (necessitated by the need for proper installation and positioning of industrial equipment or machinery), in heated buildings, and also in other industrial-type structures located in areas where the calculated mean temperature of outdoor air during the cold period is —15°C and lower, unless a vestibule or a sluice-type entrance is provided. Depending on the outdoor air temperature and number of people passing through the door per 1 hour, heated-air curtains should be provided in vestibules of buildings under the following conditions:

Outdoor air temperature, °C	Number of people
from —15 to —25	min. 400
from —26 to —45	min. 250
from —45, and below	min. 100

A common type heated-air door curtain consists of ducts with linear slots through which heated air is delivered by a fan with a velocity of 8-20 m/s at an angle of 30° to 45° to the face of the opening, against the stream of air tending to penetrate into the premises (Fig. 16).

Heated-air curtains should be installed at the gateways to the environmentally-controlled industrial buildings and structures (air-

conditioning), at the entrances to buildings in which workplaces are close to doors, also at technologically pre-designed holes and openings if they are sources of cold air and air contaminants. The temperature of the airstream for entrance doors should not be higher than +50°C, and for the gates and technological openings, not higher than +70°C. The air velocity should not be more than 5 m/s for entrance doors to auxiliary structures; 8 m/s for entrance doors to major industrial premises; and 25 m/s for factory gates and technological openings.

Emergency ventilation should by all means be installed in production areas, such as gas-generating plants and compressor houses,

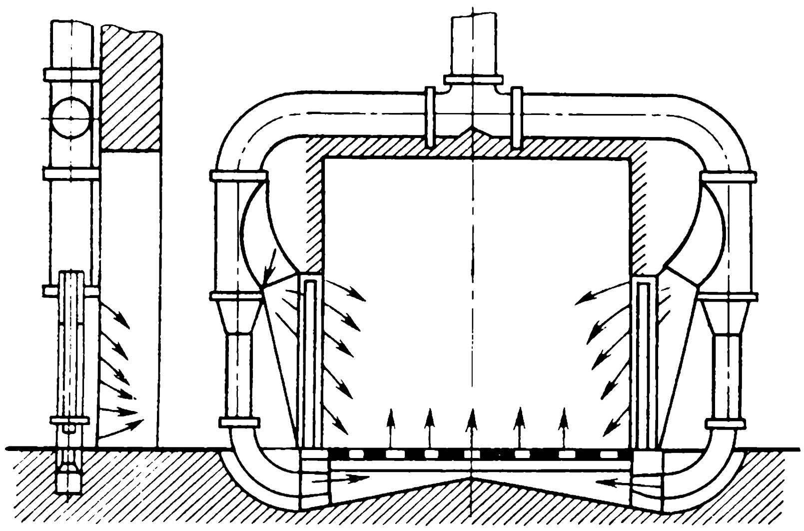

Fig. 16. A schematic of air curtain

where there is a risk of sudden outburst of explosive or flammable gases or vapors. This ventilation usually is of an exhaust type which may not necessarily use specialized air ducts for delivering air. Emergency ventilation should be designed and rated so as together with the adopted operational system of ventilation to be able to ensure at least 8 air changes per hour in industrial quarters with various kinds of production processes except for those that fall within Classes A, B, and C, under the fire-hazard classification (see Ch. 10, Sec. 2) for which emergency ventilation alone must ensure 8 air changes per hour. It has been observed that workroom temperature during the operation of emergency ventilation lowers much below normal. Axial fans commonly known for a spark-free operation are mainly used for emergency ventilation. Emergency ventilation switches on automatically when required.

Air-conditioning serves to maintain a desired environment (air temperature, humidity, purity and velocity) within production quarter regardless of the outdoor climatic conditions. Manufacturing industries use air-conditioning in laboratories where work is measurements of a high degree of accuracy and in departments whose output is high-precision instruments and devices. Air-conditioning provides

for cleaning, heating or cooling, humidifying or drying of the air before admission to the work zone. Normally, air-conditioning systems use return air except for some production processes where recirculation of air is not allowed for health reasons. All processes of conditioning the air are controlled automatically. Self-contained, general-purpose air conditioners are designed to control room temperature from +18 to +20°C, to within ±1°. Other types of air conditioners control humidity from 30 to 70%, to within ±5%. Schematically, the process of conditioning the air part of which is the return air is shown in Fig. 17. Air conditioner of this type

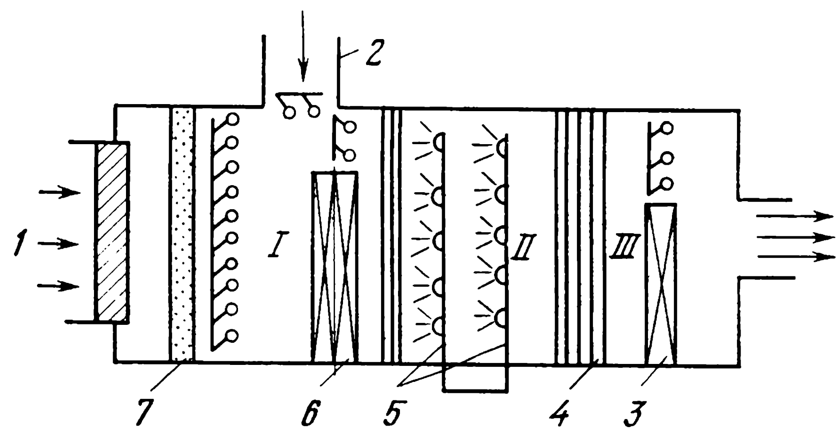

Fig. 17. A diagram of an air conditioner

I — mixing chamber; *II* — washing chamber; *III* — reheating chamber; *1* — outdoor ai duct; *2* — return air duct; *3*, *6* — heaters; *4* — drip separator; *5* — ejectors; *7* — filter

provides a complete process whereby atmospheric air is cleaned and brought to a suitable condition of temperature and humidity, mixed at two stages of the processing with portions of a valve-injected return air, washed, and again heated prior to admission to workrooms. A two-way valve is provided to control the air volumes that pass by or through the heating section of the air conditioner. The supplies of cold water to the washing chamber are controlled by a valve, and those of hot water to the heating chamber, by a three-way cock.

The choice for the use of return air is governed by reasons of saving energy. In summer the air conditioner requires too much cold water for air cooling, and in winter, hot water for air heating.

Ventilation equipment includes ventilation shafts, air ducts, ventilating fans, air cleaners and heaters.

Intake (plenum) shafts provide supplies of atmospheric air. The concentrations of harmful substances in fresh outdoor air supplies measured at air outlet points should not exceed 30% of their maximum safe concentrations. Air shafts can be separate structures or lean-to extensions (Fig. 18). Plenum shaft intakes are normally grilled with a louvre-type shutters to protect them from atmospheric precipitation. The choice of a proper size for plenum openings and

shaft sections relies on the air velocity which for openings ranges from 4 to 12 m/s, for ducts from 2 to 6 m/s.

Air ducts located inside the building are intended to convey air to production quarters or remove vitiated air from workroom at points specified by the design of the ventilation system. The choice of construction materials for air ducts is made depending largely on the medium they are supposed to convey with due regard to the fire-prevention requirements.

By fire-hazard classification, all production processes are divided between six classes, namely, Classes A, B, C, D, E and F. To

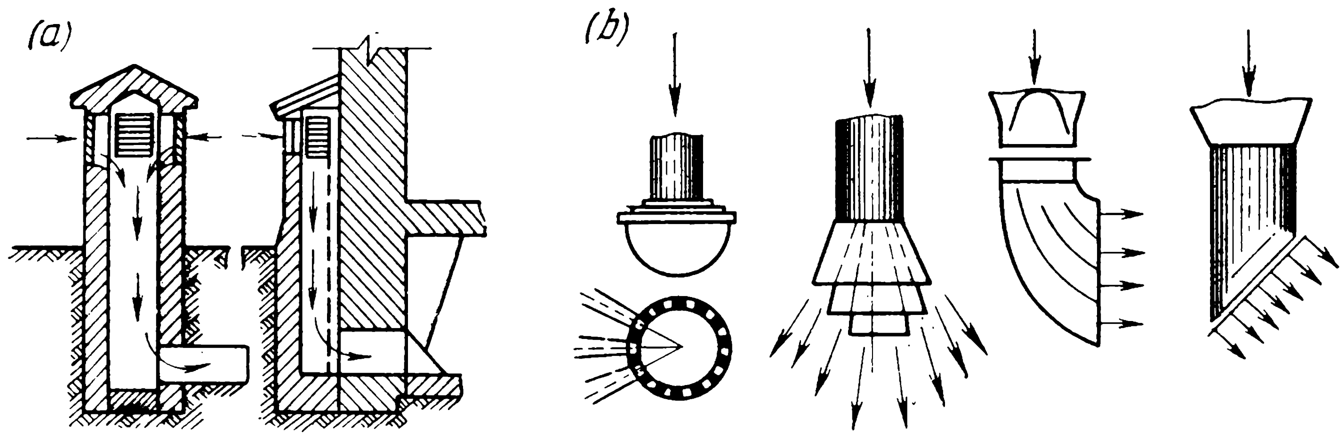

Fig. 18. Air intake and outlet devices
(*a*) shafts; (*b*) outlets

determine the fire-hazardous class of a process the reader is referred to Table 30, Ch. 10, Sec. 2 of this book, also to the code of standards for the safe design of technological processes, and to specialized lists of production processes issued by the appropriate industrial ministries and ministerial departments.

Air ducts can be round or rectangular in shape. Choice of the proper size or diameter of the air duct depends on the efficiency of the selected fan and rests on the assumption that the air velocity is high enough to prevent dust load. To minimize the air drag, the inner surfaces of air ducts are made smooth, and the branchings, bends and transitions, easy. Flange-type coupling ensures a tight connection and a joint that is easy and fast to assemble. The delivery of the air and its distribution at workplaces is effected by way of air outlets of various design, which are normally grilled branch pipes communicating with a common air duct.

Humidifiers are apparatuses for maintaining desired humidity conditions of the air supplied to production quarters. During the warm period they can also serve for cooling the air.

Air heater is a device for conditioning the air to a desired temperature before admission to industrial buildings during the cold period. An air heater of the type shown in Fig. 19 is most common.

It consists of thin-walled steel tubes arranged vertically in several rows and interconnected across the entire length by metallic plates or fins forming narrow passages of honeycomb form. At both ends, the tubes are fixed to manifolds which via branch pipes are connected to the hot water (stream) mains. Hot water or steam fed into the tubes heats the metallic plates or fins which thus become a source of radiant heat. An airstream induced by a fan passes through narrow passages between the tubes and plates and carries the heat away with it. The air temperature within certain limits is controllable.

Air ejector is a device that helps exhaust vitiated air containing flammable or explosive gases and dusts from workrooms. Schematic-

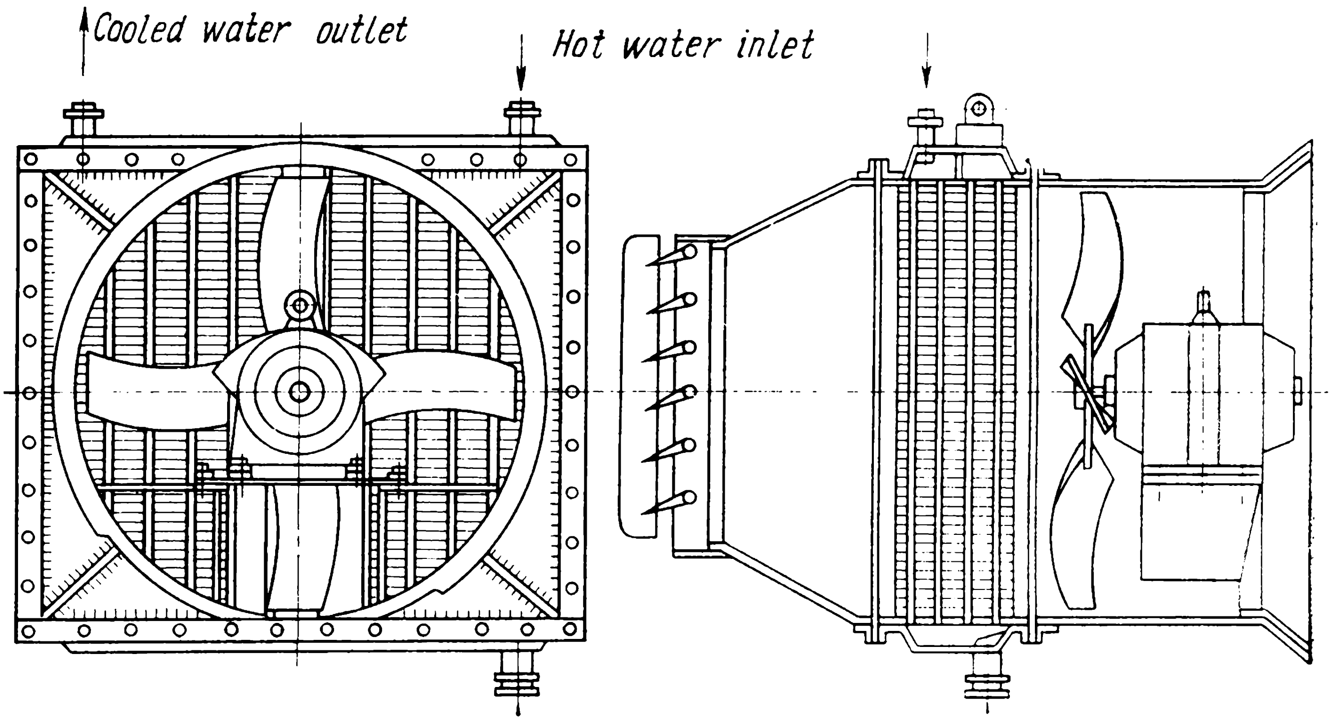

Fig. 19. Air heating unit

ally, the principle of operation of an air ejector is shown in Fig. 20. It is a type of an air pump intended to maintain a partial vacuum in diffusor *4* through the agency of a high-velocity (about 40 m/s) airstream or jet entering it via pipe *1* and nozzle *3* from source *6* located outside the room being ventilated. The airjet entrains the vitiated air in pipe *2* and exhausts it against the atmospheric pressure through air duct *5*. Air ejectors are simple in design and reliable in operation, low efficiency being their only demerit.

Fan is a device for delivering or exhausting large volumes of air or gas through a ventilation system with but a low pressure increase. By manner of action, distinction is made between centrifugal and axial fans (Fig. 21). The impeller consisting of a number of interconnected paddles or blades is an essential part of a fan of any type.

Centrifugal fan (Fig. 21*a*) has an impeller of a paddle-wheel form, a spiral jacket, a shaft, a pulley and bearings. The air enters axially

at the center of the impeller and is discharged radially by centrifugal force into the spiral jacket where it gets partially compressed. Also called paddle-wheel or radial fan.

Axial fan (Fig. 21*b*) consists of an impeller or rotor carrying several blades of airscrew form working in a cylindrical casing, sometime provided with fixed blades. Also called propeller fan. The air enters axially at the center of the impeller and is discharged centrally along its axis of rotation. The direction of the air discharge can thus be easily altered by changing the direction of the impeller rotation. Axial fans are usually driven by a direct-coupled motor, but may be geared up or down through a belt transmission by choosing suitable pulleys. Axial fans are usually used for conveying large volumes of air against small conterpressures when friction or pressure loss in the ventilation system is not more than 0.1-0.25 kPa. Normally the choice for a fan depends on the value of total pressure loss which for low-pressure systems is 1 kPa; medium-pressure systems, more than 1 to 3 kPa; and high-pressure systems, more than 3 to 12 kPa. Fans also bear numbers which, in decimeters, indicate the impeller diameter.

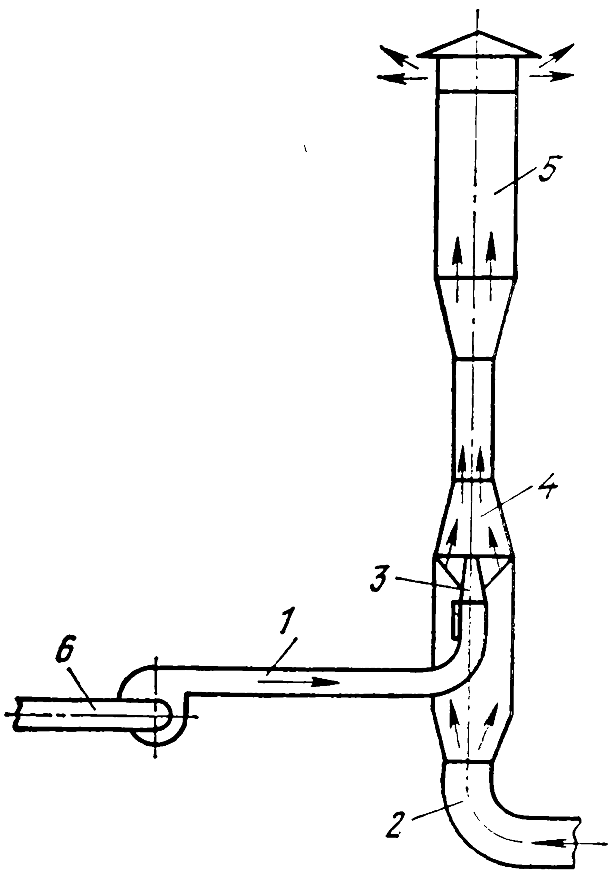

Fig. 20. An ejector

The choice for a suitable fan can be made using fan performance curve usually given in ventilation equipment catalogues. Fan characteristics can be individual and universal. The individual characteristic shows the efficiency (m^3/h) on the abscissae versus pressure (Pa) on the ordinate.

Because the efficiency and the pressure produced by a fan depend on the speed of impeller (rpm) and friction loss of the air ducts the fan characteristic is constructed for various speeds and can be used against the various pressure loss values of the air duct. Usually, the same fan operating at a given speed discharges different air volumes, depending on the friction loss of the air duct network to which it is connected.

When looking for a fan of a suitable efficiency, take the abscissae point of the necessary air discharge and find the necessary speed (rpm) and efficiency of the fan by constructing a vertical line till it intercepts the curve in a point across the ordinate. Power con-

sumption (kW) of fans can be obtained from the expression

$$N=\frac{LH}{3\,600\times 102\eta_f\eta_{tr}}$$

where L is the volume flow rate, m^3/h; H is the air duct friction loss, Pa; η_f is the efficiency of fan; and η_{tr} is the efficiency of transmission which for direct-coupled motor is 1; and for V-belt transmission, 0.9-0.96.

Air cleaning equipment. One of the basic principles of ventilation of industrial buildings is the cleaning of both plenum and exhaust air, if the last is heavily dust-laden.

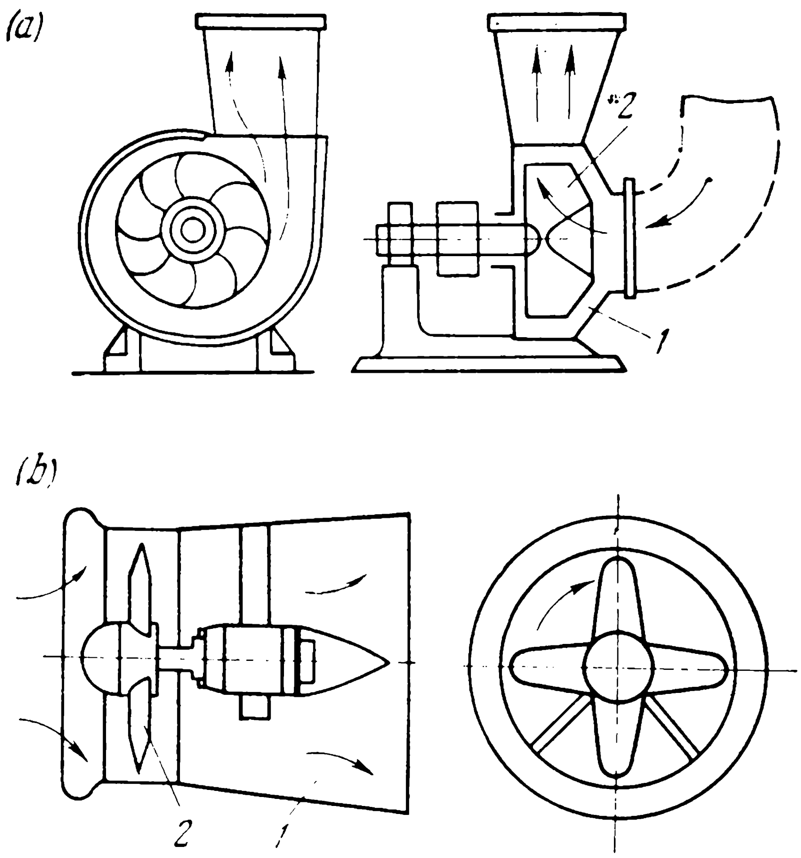

Fig. 21. Types of fan
(*a*) centrifugal; (*b*) axial; *1* — jacket; *2* — impeller

To clean the plenum air which normally has little dust, use is made of dry-porous, wet-porous and electrical filters. The exhaust dust-laden air should be cleaned before it is exhausted to atmosphere. The process is effected by means of dust collectors or catchers in which dust separation is achieved by gravity force, centrifugal force, or by bag filters. If the cleaned air contains not more than 1-2 mg/m^3, 40-50 mg/m^3, and more than 50 mg/m^3 of dust particles, cleaning is regarded as fine, medium-coarse, and coarse, respectively. There exist many types of air cleaning equipment.

Dedusting chamber (Fig. 22) is an apparatus by means of which suspended dust can be precipitated; the process is generally effected by means of an exhausting fan. The dust-laden air through air

ducts enters a chamber with a section several times that of the air duct in which the air loses its speed and dust separates from the air by pull of gravity. Only coarse dust settles in dust collectors of this type which, as a rule, constitute the first-stage cleaning for initially large content of airborne dust.

Cyclone is a type of a conical dust extractor in which dust is separated from the cyclonically rotating dust-laden air by centrifugal force. Schematically, the principle of operation of a cyclone is shown in Fig. 23. Airborne dust particles are forced against the walls of the dust separator, lose speed and settle down in the conical

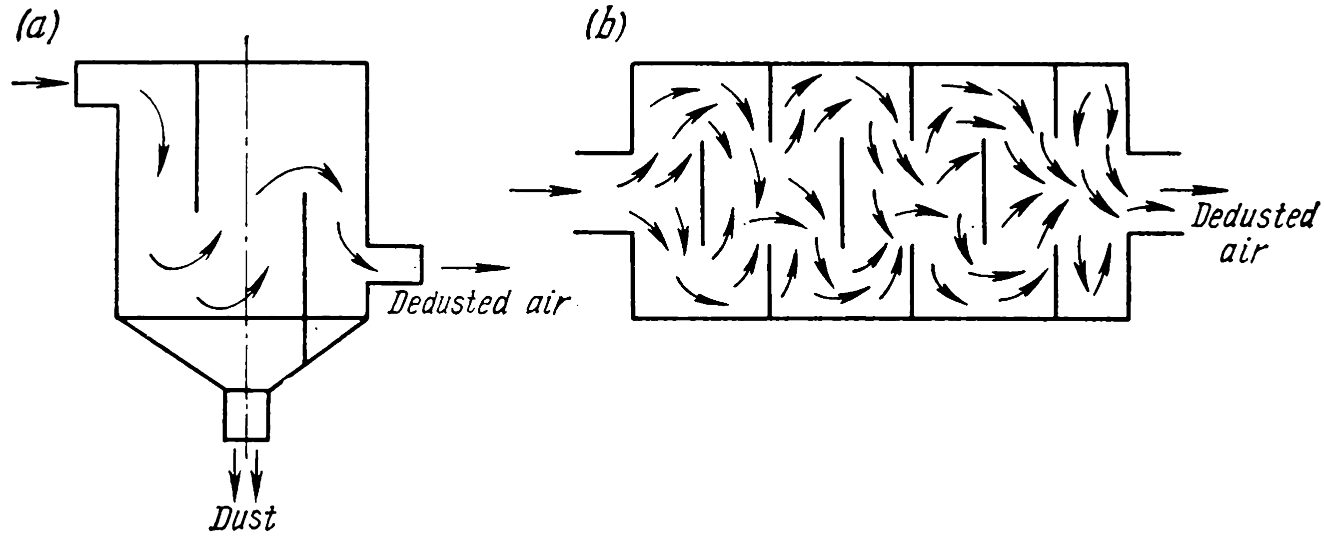

Fig. 22. Dust collectors for coarse dust particles
(*a*) with vertical baffles; (*b*) with horizontal baffles

lower portion of the collector from which the collected dust is periodically removed. Cleaned air is exhausted to atmosphere through the upper pipe.

Bag(house) filter, a widespread device for cleaning the air, is an apparatus for separating air from fine dust and consisting essentially of a canvas cloth through which dust-laden air is forced or driven by pressure of suction leaving dust particles on the outside of the canvas. It is equipped with a shaker device to regularly clean the canvas (Fig. 24). To improve the removal of dust from the canvas filter, the shaker may be assisted by back-flushing, i.e. blowing clean air through the canvas from the inside. Baghouse filters produce a high degree cleaning (99%) when catching dust particles sized from 0.3 to 4 μm. Their disadvantages include large dimensions, need for frequent removal of the collected dust and filter cleaning for, as the cloth resistance of the filter increases, its capacity lowers.

An air cleaner in which the filtering medium is Rashig rings or goffered screens impregnated with a viscous non-vaporizable fluid are known as *oil filters*. Oil filters are used for fine cleaning of the air in which dust concentrations are up to 10-20 mg/m^3. Depending on the size of dust particles, the filtering capacity of

such filters varies from 80 to 99%. Oil filters are effective for fine dust particles which stick to the oily surface of the screens or Rashig rings (Fig. 25). Self-cleaning oil filters are effective for dedusting the air with initial dust concentrations of 20-30 mg/m^3, with a degree

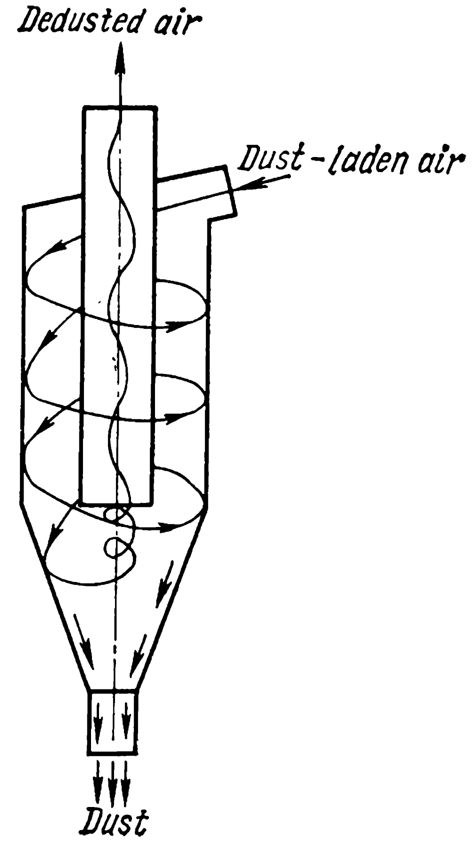

Fig. 23. Cyclone dust separator

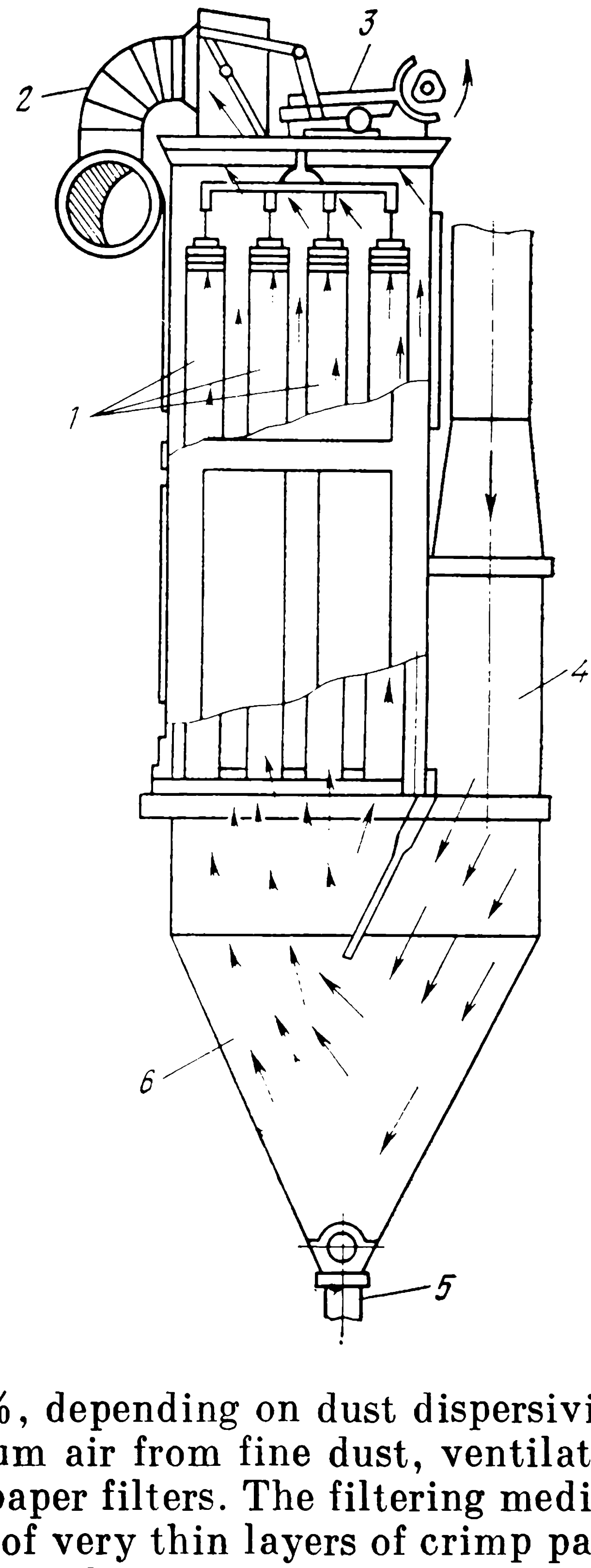

Fig. 24. Baghouse filter
1 — bags; *2* — cleaned air outlet; *3* — shaking device; *4* — exhaust duct; *5* — dust disposal hole; *6* — dust bin

of dust separation of about 80-98%, depending on dust dispersivity.

Paper filters. To clean the plenum air from fine dust, ventilation systems employ air cleaners with paper filters. The filtering medium is pure cellulose made in the form of very thin layers of crimp paper and packed into stacks of a definite thickness.

Filter paper for quantitative purposes is treated with acids to remove all or most inorganic substances. The disadvantages of paper filters are relatively high resistance to airstream and frequent need for changing the filter paper stacks. Besides, paper filters are impracticable for high concentrations of dust as their resistance to

the air passage increases, and this demands for immediate replacement as it reaches 120-150 Pa. The efficiency for fine dust separation is 92-95%.

Electrical precipitators (Fig. 26) are dust collectors in which the process of dust separation is effected by an electrical precipitation

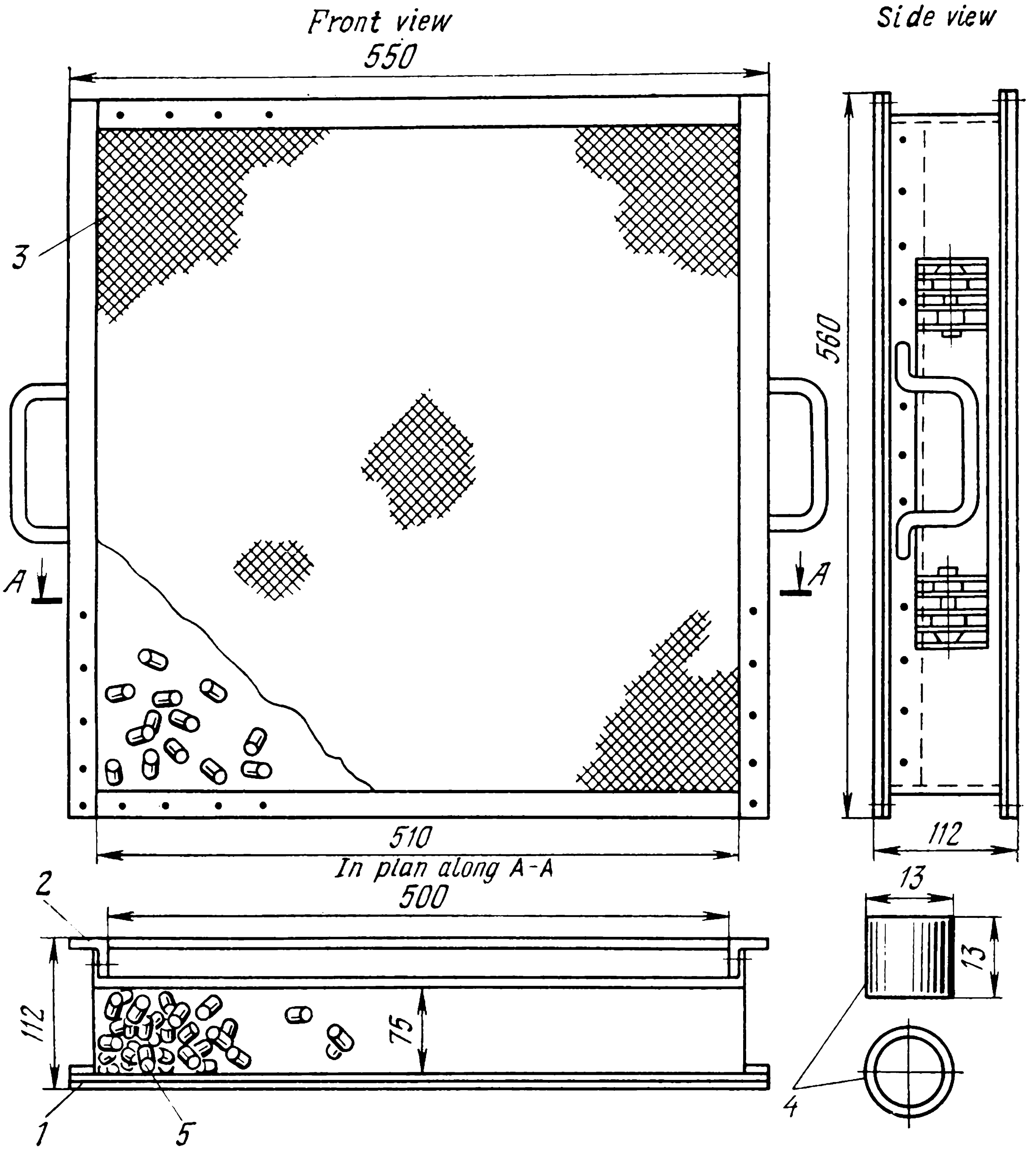

Fig. 25. Oil filter deduster

1 — casing; 2 — lid; 3 — screen; 4 — spacer; 5 — Rashig rings

plant using a unidirectional electric field in which airborne dust particles are attracted to, and collected on, the positive electrode from which dust is shaken off into a dust bunker. Also called electrostatic precipitators whose separation efficiency for fine dust is 95-99%.

The choice of a filter or dust arrester is based largely on the required degree of cleaning, content of dust in the dust-laden air, nature

of dust and size of dust particles, efficiency and pressure of the ventilating unit, resistance and capacity of the dust separator (Fig. 27).

The physical properties of dust are also important. Thus, inertia-type dedusters and baghouse filters are ineffective for sticky moist or fibrous kinds of dust. Dust collectors, cyclones or electrical precipitators are usually ineffective for dusts in which the vast majority of particles are less than 10 μm in size.

Content of dust suspended in the air is also important for choosing an air cleaner of a suitable type and capacity.

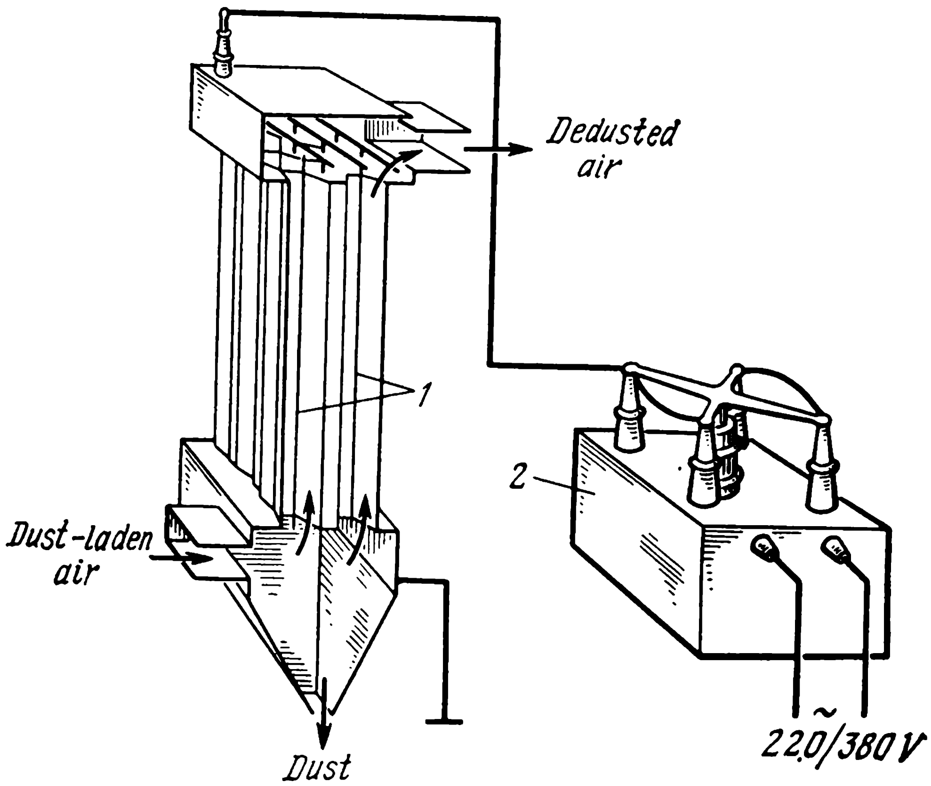

Fig. 26. Electrostatic precipitator
1 — corona-forming electrode; *2* — dust-collecting electrode

The efficiency of dust separation of the air cleaner is determined as the percentage ratio of the difference between the initial and final dust content to the initial dust concentration in the air:

$$\eta = \frac{d_1 - d_2}{d_1} 100$$

where d_1 is the dust content in the air before the cleaner, g/m^3; d_2 is the dust content in the air after the cleaner, g/m^3.

If we have to compare two filters or dust collectors with $\eta_1 = 90\%$ for the one and $\eta_2 = 95\%$ for the other, the efficiency of the last would be $(100 - 90)/(100 - 95) = 2$ times and not 5% higher.

Another important condition for selecting an air cleaner is the maximum permissible mass concentration of dust in the cleaned air, i.e. after the cleaner. Thus, with $d_1 = 4$ mg/m^3 and the maximum permissible $d_2 = 0.5$ mg/m^3, the efficiency of the dust collector

should be not less than

$$\eta = \frac{4-0.5}{4} 100 = 87.5\%$$

To facilitate precipitation of fine dust some dust collectors use washers to wet the dust particles and force them to stick together to produce larger particles.

Industrial ventilation is a complex installation that requires skilled personnel and specialized training for proper operation and maintenance. The manufacturer's certificate and specifications, operating regulations, and a maintenance book-register should be available for each ventilation unit.

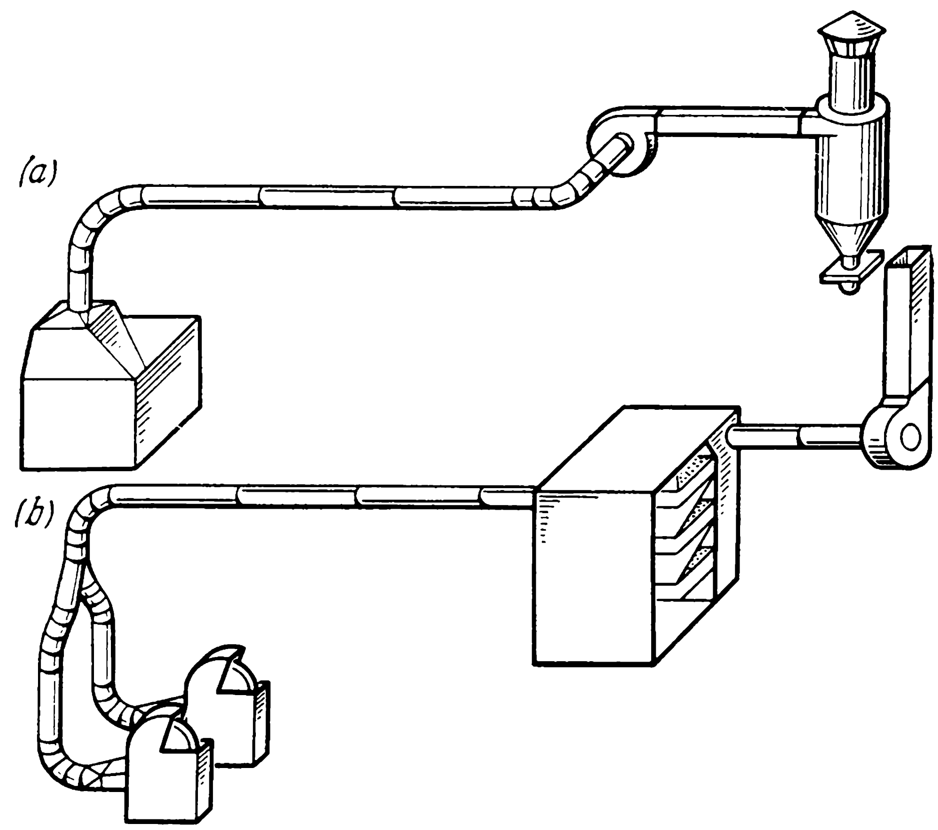

Fig. 27. Exhaust-ventilation installations to clean the air
(*a*) after fan; (*b*) before fan

Operating regulations should include instructions for the correct startup and shutdown, maintenance and repair, and operating parameters. All the data on time, kind of servicing and repair works, nature of trouble and its elimination, and trial runs should be recorded in the register. When testing a ventilation system for various parameters, the ventilating fans should be checked for total efficiency, total and static pressure, and speed.

2.5. HEATING

Heating of all industrial buildings and other premises (also crane cabins, control rooms and other separate enclosures) is obligatory to ensure and maintain normal air temperature at workplaces and in the work zone.

Much heat is usually lost during the cold period by conduction through the walls of buildings and by escape through openings, doors and window untight closures, and much heat is required to heat up the air that enters into the industrial building through the doors and gateways frequently opened to let in and out people and vehicular transport handling various materials.

Heat losses by transfer through the walls are the largest and can be determined by the formula

$$Q = KA\ (\Theta_{in} - \Theta_{out})$$

where K is the heat transfer coefficient, W/(m²K); A is the area of the enclosure walls, m²; Θ_{in} is the indoor air temperature, K; Θ_{out} is the outdoor air temperature calculated depending on the undertaking's geographical locality, K (reference data).

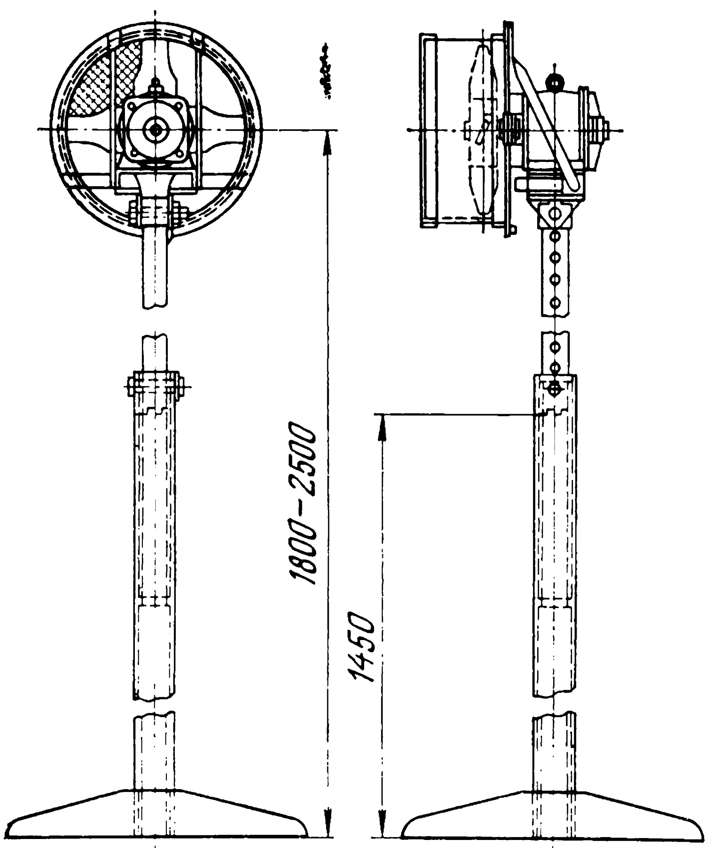

Fig. 28. Portable air douche unit

Depending on the heat-transfer agent or medium, heating systems can be divided into hot-water, steam, heated-air, and mixed systems.

The hot-water heating system is the most common as it suits best both the operating and hygienic requirements.

The steam-heating system is practicable for the undertakings which generate or utilize steam for technological purposes. The temperature of the steam-heating devices is usually high and may lead to fire hazards and unpleasant odors produced by dust burning. The external surfaces of such heaters are usually made smooth to prevent dust accumulation and facilitate cleaning. When local heaters are used, the temperature of the heat-transfer medium should be not more than 150°C for hot water, and 130°C for steam.

By manner of delivering heated air, the air-heating systems can be *central* and *local.* In the first system the air is heated by a central unit and is forced through air ducts to workrooms. An example of the local air-heating system can be an apparatus including an air heater and a fan, and installed in a workroom to be heated. The heat-transfer agent can be obtained from a central hot-water or steam-heating system. Local electrical systems for heating the air can also be used (Fig. 28).

2.6. INSTRUMENTATION

To ensure proper environmental control, the climatic parameters within an enclosure should be periodically checked and measured. Various kinds of measuring instruments can be used for this purpose.

Thermometers, placed on the walls or columns 1.5 m high above floor level and not closer than 1 m to the heating device, are used

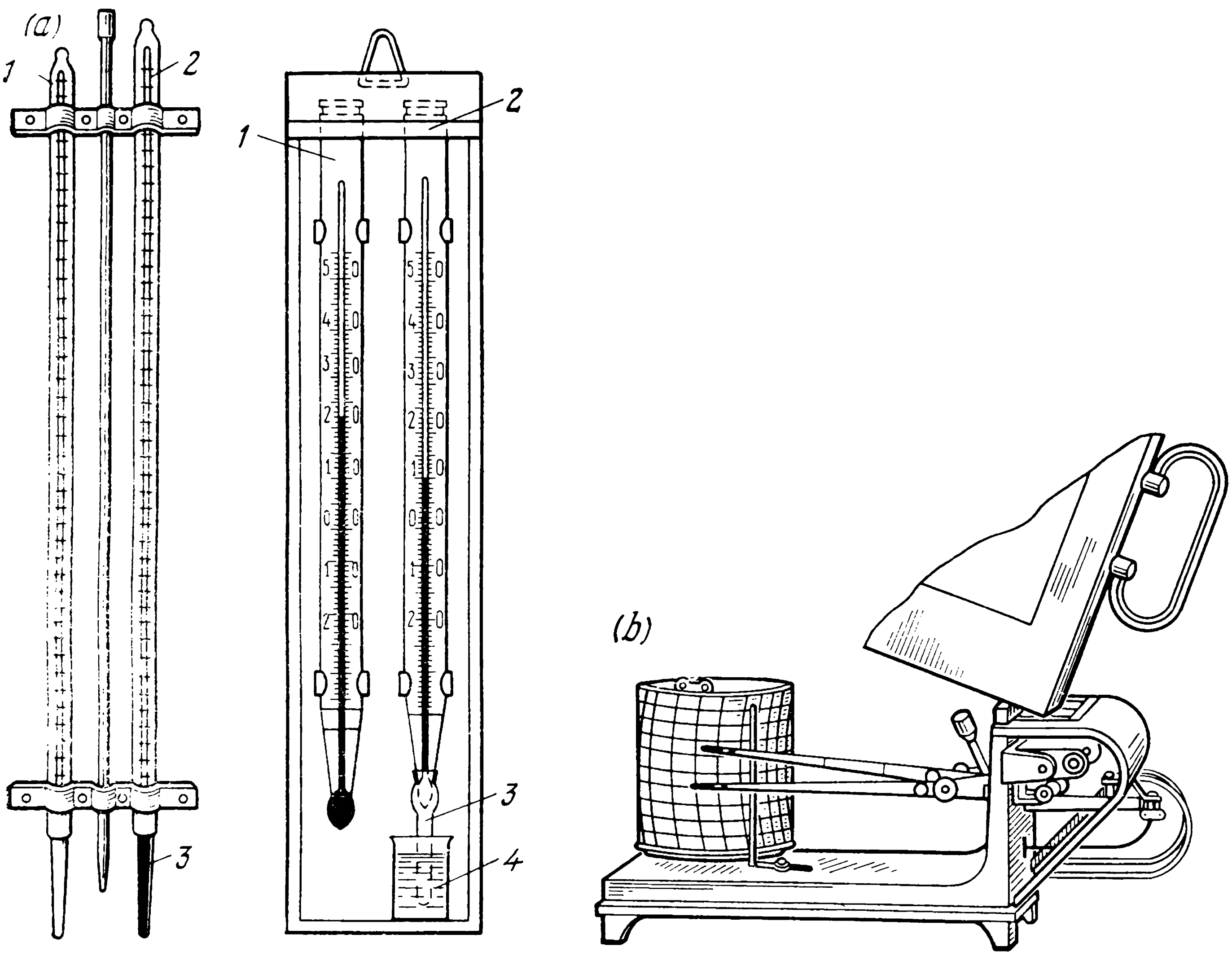

Fig. 29. Instruments to measure air temperature and humidity
(*a*) static psychrometer; (*b*) hydrograph

to measure the air temperature. Careful temperature control is necessary for Class I jobs. In such cases, *thermographs* are used for continuous recording of the air temperature in the workroom. Thermographs can be of two types: the one for a continuous 24 h recording, and the other for a continuous week recording of the air temperature.

Psychrometers, or wet and dry bulb hydrometers, are devices used to determine the relative humidity of the air by the difference in the readings of a pair of similar (mercury or alcohol-filled) thermometers (*1*, *2*) mounted side by side. The one (*1*) is a "dry bulb", and the other (*2*) has its bulb wrapped (Fig. 29*a*) in a damp wick (*3*) dipping

into a distilled water (*4*). The rate of evaporation of water from the wick and the consequent cooling of the "wet bulb" is dependent on the relative humidity of the air which can be obtained by using a psychrometric table, or a nomogram (see Fig. 2), from readings of the two thermometers. Use is also made of stationary aspiration psychrometers which are equipped with a fan to draw the air through the device and increase the accuracy of measurement.

Hydrographs are used for continuous recording of the air humidity where the humidity requirements are most stringent (Fig. 29*b*).

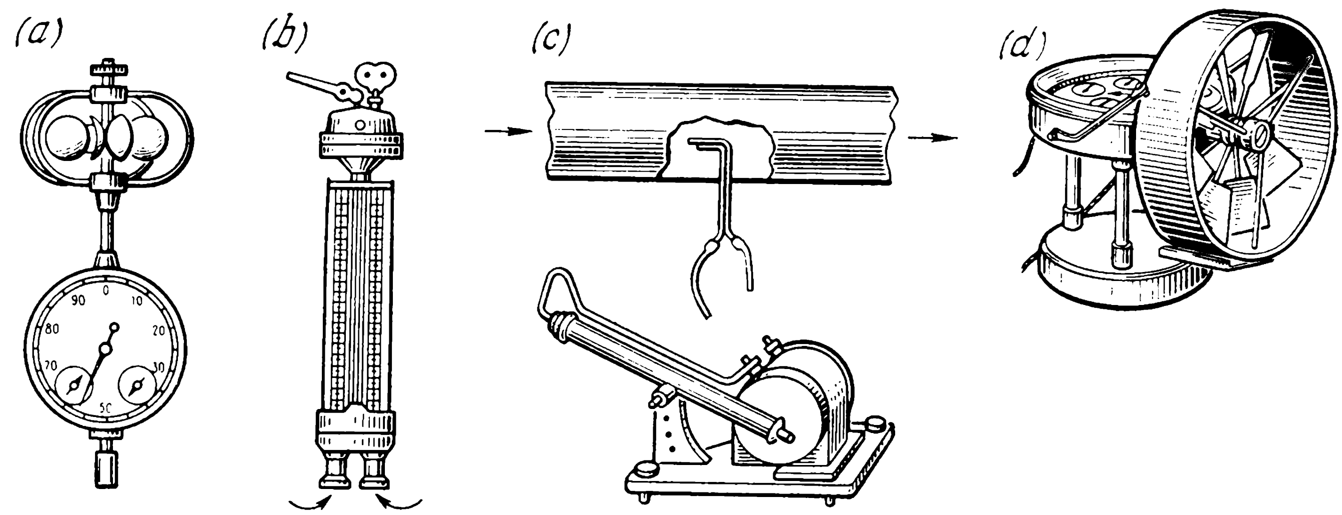

Fig. 30. Instruments to test ventilation installations
(*a*) cup anemometer; (*b*) psychrometer; (c) micro-pressure gage; (*d*) vane anemometer

Anemometers are instruments for measuring the velocity of the air. The common types are the revolving-vane and the revolving-cup anemometers (Fig. 30*a* and *d*).

A common anemometer of the vane type consists of eight vanes fixed on a hub at 45° to the airstream and pivoted so as to be capable of rotation in a vertical plane. The speed of rotation is indicated on a dial calibrated to read air velocity from 0.3 to 5 m/s.

The cup anemometer differs from the vane type anemometer in that it consists of four semispherical cups carried on the ends of four radial arms pivoted so as to be capable of rotation in a horizontal plane. The speed of rotation is indicated on a dial graduated to give velocities of airstream from 1 to 20 m/s.

Airstream velocities under 0.3 m/s are measured by means of a microanemometer or electrical-thermal anemometer.

Pressure tubes are used to measure both pressure (total and static) and velocity of the air in air ducts. The dynamic (velocity) pressure is determined as the difference between the total and the static pressures. The air velocity in air ducts can be measured with a pressure head device (which is a combination of a static and Pitot tube connected to the opposite sides of a differential pressure U-gage to give a visual reading corresponding to the speed of an air current).

Indication tube is used for measuring contents of air contaminants

(largely toxic vapors and gases such as CO, SO_2, nitrogen oxides, ethanol, etc.). A common type is a hermetically sealed glass tube about 4 to 7 mm wide and 100 mm long containing a filler (crushed silicagel, glass, or porcelain crumps) treated with solutions of various reagents. It also has chemical absorbents to bind unsuitable substances that may prevent proper determination. To make an air analysis, a measured quantity of air is brought into intimate contact with the contents of the open tube for a certain time interval, and the concentrations of the controllable impurity can be read on a scale by length or rate of change in color of the filler material that has completed reaction.

Purity of the air can also be measured by air or gas analyzers of various design. Direct techniques of gas analysis—spectrometry, electric-chemical, and optical methods permit the analysis of the air to be performed continuously and automatically.

The sampling method implies that samples of air are analyzed in a laboratory by trained specialists. Although the process is lengthy and costly it provides accurate measurements necessary for the adequate air control.

Dust contents in the air of workrooms are determined by passing a measured quantity of air through filters during a particular time interval and calculating the mass of dust thus collected. There exist also several other proximate methods of quick determination of the character of dust and size of dust particles.

2.7. PERSONAL PROTECTIVE EQUIPMENT

The safety regulations on the personal protective equipment contain a comprehensive summary of safety requirements regarding the use of means of personal protection, such as working clothes, safety goggles, gloves, shoes, don helmets, etc. Personal protective equipment should provide the best body-environment relationship and optimum safe conditions of work. The protective devices themselves should not cause, or be the sources of, industrial hazards but be effective and convenient in use and satisfy the requirements of ergonomics and industrial aesthetics.

Resort to personal protective equipment is made if the elimination of the hazard to prevent accidents by the design, organization of process, architectural or planning solutions is impossible.

Working clothes should be selected with due consideration to the hazards to which the wearer may be exposed. These hazards may be of the mechanical, physical and chemical origin (unguarded or moving parts of machines or equipment, radiant heat, acids and alkali, etc.). In all cases, those types of working clothes should be selected which will reduce the hazards to the minimum attainable

in each case (provide cover of the body, fit well so as not to restrict freedom of movement, be conducive to thermal control, washable and durable).

Goggles. One of the most difficult problems in accident prevention is the prevention of eye accidents. Quite satisfactory safety goggles are now available to the worker. It is not however enough to have good goggles, they must be worn and much effort in the way of disciplinary, education and persuasion may be required to make workers use them.

There are various kinds of eye accident, and different types of goggles have been found necessary according to the work to be done. For instance, goggles for the workers engaged in chipping, riveting, caulking, scaling, dry grinding or similar operations in which flying fragments could pierce the eye have to have mechanically strong lenses, while the goggles the welders, furnacemen and other workers exposed to glare have to have suitable filter lenses.

Safety shoes should protect workers against accident caused by heavy objects dropping on the feet, protruding nails, molten metal, acids, etc. To be really safe, the worker has to wear shoes made of chemically resistant materials with built-in steel toe caps, and knurled soles to give good balance and prevent falls by slipping or tripping. Sometimes special kinds of footwear are necessary to protect from low temperatures (up to —30°C), from dust, etc. For instance, electricians should wear non-conducting shoes, and workers in explosive factories, non-sparking shoes (in both cases without metal nails).

Gloves should be given to workers with due consideration to the hazards and the need to allow free movement for fingers and hands. The kind of gloves required may vary with the injury to be prevented (puncture, cut, heat or chemical burn, electric shock, radiation burn, etc.). It should be remembered that it is dangerous to wear gloves when working at drilling machines, power presses and other machines in which a glove can be caught.

Hard hats or helmets sufficiently strong and not too heavy should be distributed to workers liable to be struck by falling or flying objects or otherwise exposed to head injuries. Plastic hard hats with a cloth lining have proved to be most suitable.

Aprons of various materials may be useful to protect workers against chemical or heat burns, wet or oil, but they should not be worn when working near machines.

Ear protection. Ears should, if necessary, be protected against sparks, splashes of molten metal or other flying particles. Protection against harmful noise will be dealt with later in the book.

Lung protection will be required whenever there are undue quantities of harmful elements or a deficiency of oxygen (below 18 percent by volume) in the atmosphere. The subject of respiratory protection

is more in the field of health than of safety. In some countries however cases of gassing are considered as accidents.

Equipment for lung protection includes air-purifying respirators and gas masks.

Many types of respirators exist of which the particulate filter respirator, aerosol filter respirator, chemical-cartridge respirator and spray mask are the commonest.

The filter-type respirators (Fig. 31) are designed entirely for respiratory protection. A common type consists of a face piece which

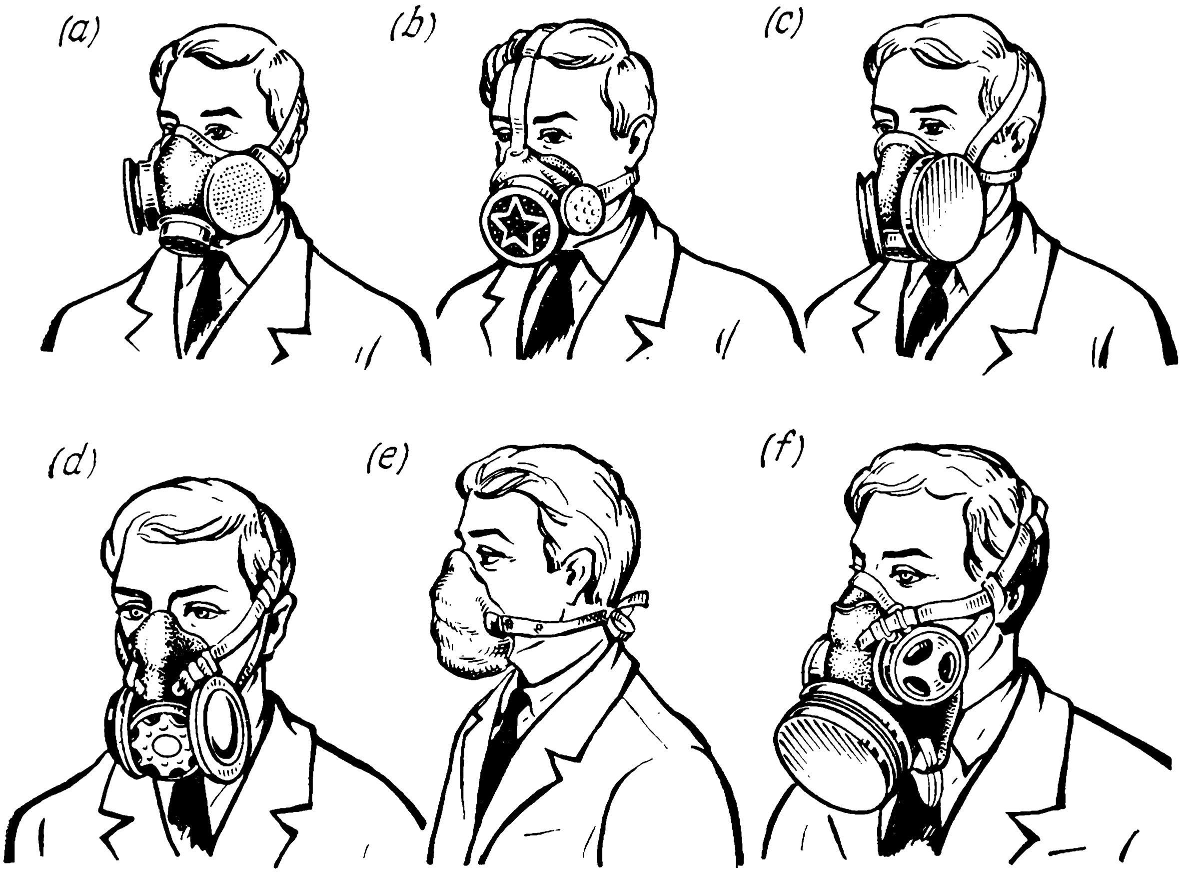

Fig. 31. Dust-fighting respirators

(*a*, *e*) with crimp paper filter; (*b*) with cotton filter; (*c*) with paper-leaf filter; (*d*) with felt filter; (*f*) with fabric mat filter

is a frame with a filtering mat of fine fibre, attached to a band or strap and worn about the head. By purpose, air-purifying respirators can be dust- and gas-fighting, and general-purpose respirators. Some may have a rubber half-mask supplied with two chemical cartridges. General-purpose respirators can be used in the atmosphere with small concentrations of harmful elements, such as gases, vapors and dusts, and are supplied with a replaceable aerosol filter and a chemical cartridge.

A constant-flow airline spray mask can be regarded as a variety of respirator. Designed to protect the worker from airborne paint and other atomized materials, it consists of a half-mask face piece, a coupling union to receive an air-line from a respirable air source

(compressor unit), a filter to clean compressed air, and an exhalation valve.

Gas masks can be of a filter or hose type, and self-contained (oxygen-generating, pressure-demand) breathing apparatuses (Fig. 32).

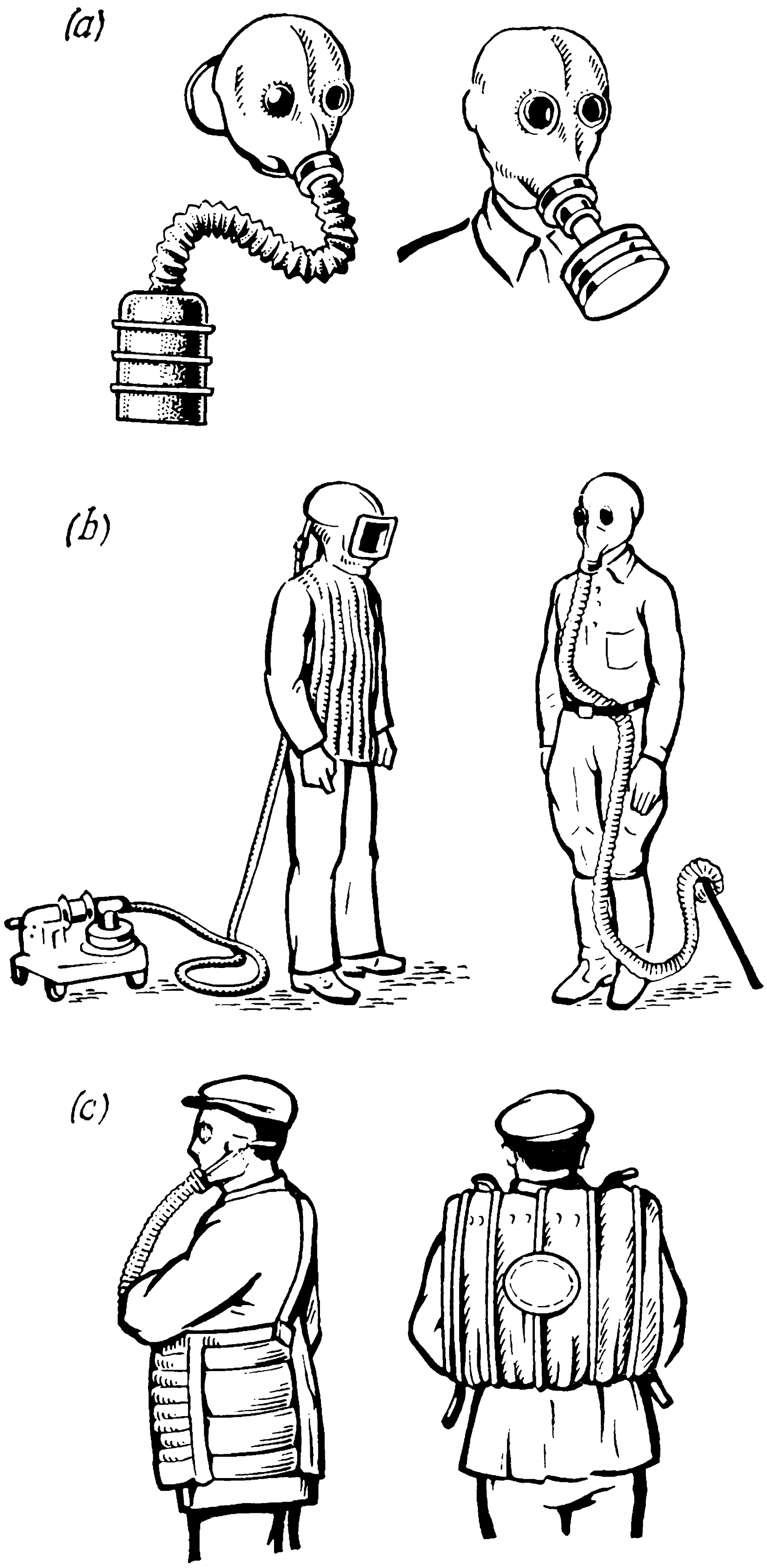

Fig. 32. Personal lung protection equipment
(a) gas masks; (b) hose mask; (c) oxygen-generating breathing apparatus

The filter-type gas masks are designed to protect the lungs, eyes and the skin against harmful elements. A commercial-type gas mask consists of a full-face piece, filter box with or without a corrugated

hose, and a shoulder strip bag. Face pieces are made to measure of five head sizes. The filter box is replaceable and can bear different identification colors according to the kinds of vapor and aerosol from which it is supposed to protect. The length of protective action varies from 40 to 360 min, depending on the content of harmful elements in the air, air temperature, humidity and air velocity.

Hose masks with a blower include a face piece, corrugated hose, rubberized fabric air-line, air filters. The blower is used to supply air to the face piece through the air-line, at which other end is the filter box usually positioned at a safe distance, i.e. about 10 m from the workplace. A complete set includes also a safety belt and lifeline for workers in confined and badly ventilated places, such as tanks or bins.

Barrier creams and detergents are used to protect from skin injuries and dermatological disorders. Barrier creams fall under two groups: barrier creams against petrochemical products, solvents, grease, varnishes and organic paints; and creams against acid and alkaline solutions, salts, and cutting emulsions.

Detergents are used to remove barrier creams and clean the skin from other oily materials.

CHAPTER 3

Industrial Lighting

Lighting is the illumination of the surfaces of objects in order to make the objects visible or discernable to light-sensible substances or devices.

Man obtains most of his information about the outside world by means of sight. This is a fact that explains the importance of illumination. The optimality of visual information in a manufacturing undertaking can be achieved only by the rational illumination of workrooms and workplaces. Good illumination generally improves the working conditions and raises the productivity of labor (Fig. 33). Illumination is also beneficial to a person's general physiology, inducing a psychological state that is favorable for work or relaxation, and therefore, is of major importance to good health.

To the extent that accidents result from fatigue, adequate lighting is a preventive measure. The relation between poor illumination and high accident rates has been demonstrated in quite a number of publications. Investigations into the relation between production and lighting have shown that adequate illumination, arranged to suit the type of work to be done, may result in a maximum of production and a minimum of inefficiency and thereby in all probability help indirectly reduce the number of accidents.

As a safety factor in the physical environment of the worker, lighting is important to provide normal working conditions and suit best the type of visual task to be performed.

Illumination should provide a surface illuminance that is both adequate and uniform, and a suitable distribution of brightness in the surrounding space. Work zones should be so lighted as to give the worker a clear vision of the process, tool or workpiece at a distance of more than 0.5 m to the eye.

The light sources should be free of glare, the spectral distribution of the light should be favorable, and the light beams should have a proper incident direction. The standards require a uniform illumination of work surfaces, absence of fluctuations and abrupt changes of illuminance, and minimization or elimination of any visual

discomfort or any dazzling condition that can arise from excessive brightness within the field of vision, or from direct glare from the light source. Standards also require elimination of any undesirable glare from illuminated surfaces in the direction of the eye.

The economics of improved illumination are such that in most cases the expenses are justified. Illumination that satisfies requirements of both health and economics is called *rational*. Health requirements are based on the study of the most important characteristics

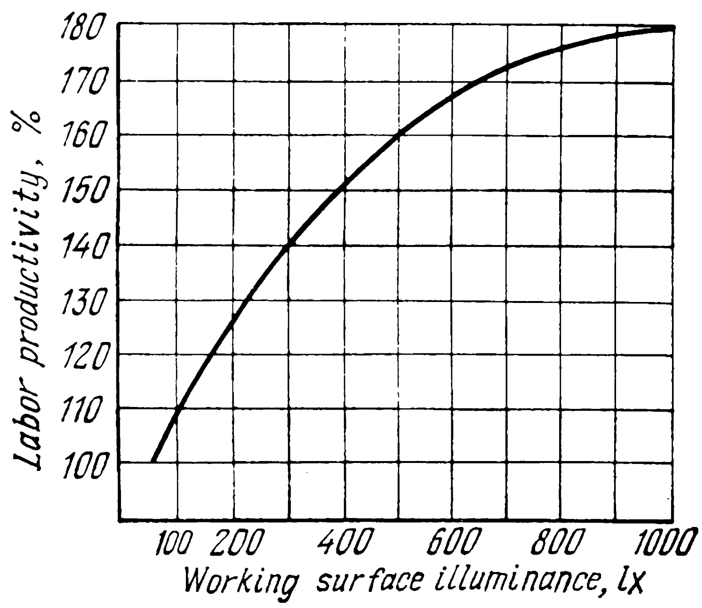

Fig. 33. Labor productivity *vs* illumination

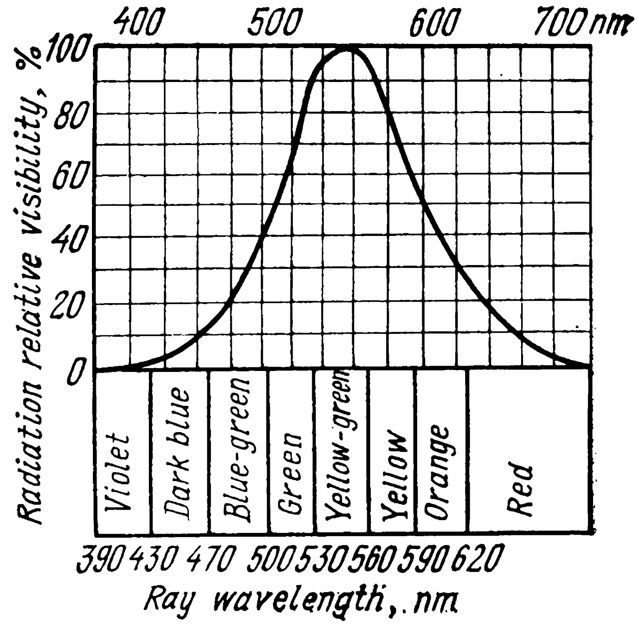

Fig. 34. Color of spectral region *vs* light ray wavelength

of human vision, such as visual acuity, sensitivity of the eye to contrast and color, rapidity of visual perception, and clarity of vision. A rational illumination of industrial premises requires general illumination of the entire area to increase the safety of vehicular and pedestrian traffic, and render visible structural elements of the buildings and equipment parts, workpieces and other articles that may be stored on the floor and obstruct passage. In designing illumination for industrial premises or workplaces, it is necessary to take into account the degree of precision required for the work, the contrast between the object to be discerned and the background, the necessity of discerning distant or rapidly moving details, the duration of the visual work.

The human eye has the ability of accommodation and adaptation to rapidly changing conditions of the environment.

Accommodation is the ability of the eye to change its effective focal length in order to see or discern objects distinctly at varying distances. The object to be discerned can be any item or article, part or detail of it, or a defect on the item (e.g., cloth thread; point, scribe mark or match mark; character, etc.), which is essential for the work being performed.

Adaptation is the sensitivity adjustment of the eye effected after considerable exposure to light (light-adapted) or darkness (dark-adapted).

Dazzling conditions and frequent adaptation may cause visual fatigue and occupational eye troubles which are conducive to accidents.

3.1. LIGHT AND CRITERIA OF ILLUMINATION

In the narrow sense, *light* is visible radiation, that is, electromagnetic waves within the range of frequencies perceived by the human eye. This range extends from 7.5×10^{14} to 4.3×10^{14} hertz (Hz) and corresponds to the range of wavelengths in a vacuum from 400 to 700 nanometers (nm). The eye is able to detect light of very high intensity in a somewhat broader frequency range. In the broad sense, light is optical radiation and includes radiations in the visible, ultra-violet and infrared regions of the spectrum. The range of frequencies in this case extends from about 3×10^{11} to about $3 \times \times 10^{17}$ Hz; the corresponding range of wavelengths in a vacuum is from 1 mm to 1 nm.

The optical spectra, the luminous (electromagnetic) radiation capable of inducing visual sensation through the eye within the range of wavelengths from 10 to 340 000 nm, can be divided, depending on wavelengths, into the ultra-violet region (from 380 to 10 nm), the visible region, i.e. light (from 770 to 380 nm), and the infrared region (from 340 000 to 770 nm). In the visible region of the spectrum (Fig. 34), colors from violet (380 nm) to red (770 nm) are recognizably visible.

Luminous radiation exerts a certain influence on the human body, the nervous system and the psychological state of man. It can change pulse rate, intensity of certain metabolic reactions. Optimum light conditions, i.e. degree of illumination, influence favorably the general state of the body and improve working efficiency. However, sufficient amount of light at workplaces is not enough for a rational lighting of industrial premises for the quality of illumination is also very essential. The qualitative characteristics of lighting include uniformity of light (luminous flux) distribution, incidence of abrupt changes of illuminance, contrast between the object and background, etc. Proper illumination of industrial premises cannot be achieved if light sources or light openings are distributed about the building at random. Adequate illumination requires good knowledge of the fundamentals of lighting or illumination engineering, specific requirements of the manufacturing process, standards for illumination of industrial buildings and practical experience.

The quantities used in illumination engineering to qualitatively evaluate lighting are based on the study of the sensations that arise

from the effect of luminous radiation on the human eye. These quantities are the luminous (also light) flux, luminous intensity, illuminance, luminance (or brightness), and reflectance, or reflection factor.

Luminous flux is the quantity of light emitted per second by a light source. Stated differently, it is the radiant power, i.e. rate of propagation of radiant energy evaluated by the visual sensation of the human eye. The unit is the lumen (lm), and the symbol F.

Luminous intensity is the luminous flux emitted per unit of solid angle (the measure of spatial density of the light flux) in a given direction. It is equivalent to the ratio of the luminous flux to the solid angle[1] within which the distribution of the light flux is uniform. The unit is the candella (cd), and the symbol I:

$$I = F/\omega$$

where ω is the solid angle.

Illuminance is the luminous flux that strikes a unit area, equal to the ratio of the light flux F to the surface area S. Stated differently, illuminance is the surface density of the light flux distributed uniformly over the surface. The unit is the lux (lx) which is equivalent to 1 lm/m² (Fig. 35), and the symbol E. The mean illuminance, if the light is normally incident on the surface, can be determined by the formula

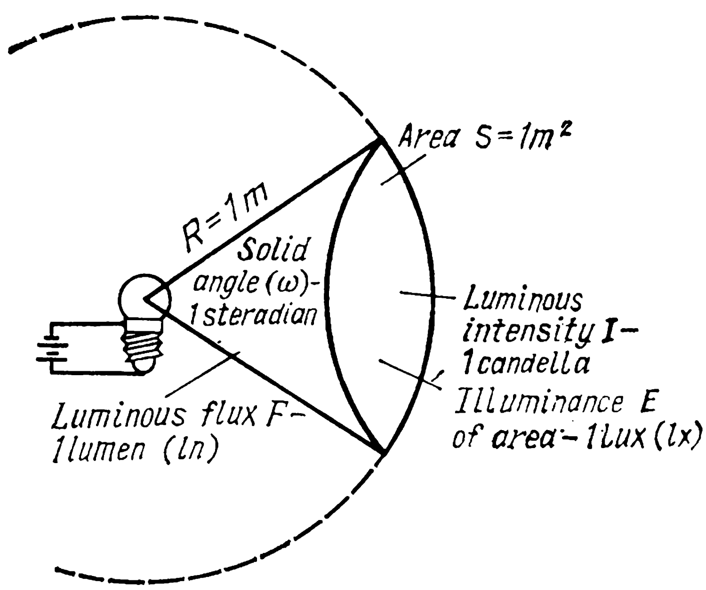

Fig. 35. Basic concepts, units and symbols used in illumination engineering

$$E = F/S$$

When calculating artificial illumination of industrial premises, the concept of mean illuminance usually applies to a horizontal plane 0.8 m above the floor level, also known as the workplace plane.

Luminance (or *brightness*) is the luminous flux (directly perceived by the eye) reflected by a surface in a given direction. The unit is the candella per sq.m (cd/m²), and the symbol L. All other con-

[1] Solid angle is the area on the surface of a unit sphere intercepted by the cone whose base is the area and the apex of the point which is also the centre of the sphere. It is defined as the ratio of the area S, which the cone intercepts on the sphere surface, to the squared radius R of this sphere. The unit is the steradian (SR) and the symbol ω: $\omega = S/R^2$.—*Translator's note.*

ditions being equal, the luminance is proportional to the illuminance,

$$L = I\rho/S$$

where ρ is the reflection factor of the surface.

Reflection factor is the ratio which the luminous flux (F_{ref}) reflected from a surface bears to that (F_{fal}) falling on it; also called the coefficient of reflection:

$$\rho = F_{ref}/F_{fal}$$

Beside the quantitative indices, the qualitative characteristics of illumination, such as the background, contrast between the object to be discerned and the background, light dazzle or blinding factor are also essential for a rational lighting, and as such should, by all means, be taken into account.

Background is the surrounding surface, either real or artificial, against which the object can be visualized or discerned. The background is said to be light if the reflection factor is greater than 0.4, semi-dark, if the reflection factor is 0.4-0.2, and dark, if it is less than 0.2.

Contrast is the relative luminance (brightness) between an object and its background (e.g., a letter on white paper); the symbol C. In other words, the contrast between the object and its background is the photometrically measured difference of the luminance of the two zones; and where the background has a luminance L_1 and the object a luminance L_2 (L_1L_2) it can be expressed thus:

$$C = (L_1 - L_2)/L.$$

Contrast is a dimensionless value ranging between 0 and 1. Contrast is said to be *high* if the difference in brightness between the object and background is great; *soft*, if the difference is not very significant; and *low*, if the difference in brightness is but hardly recognizable.

Illumination can be natural, artificial, or mixed.

3.2. NATURAL ILLUMINATION

Natural illumination is created by natural light sources, such as the sun or the moon, and varies considerably depending on such factors as the time of day and year, the geographic latitude of the locality, and atmospheric conditions. Natural illumination in open spaces produces the following illuminances on horizontal surfaces: 0.0005 lux for a moonless light; up to 0.2 lux in the light of a full moon; and up to 100 000 lux in direct sunlight. The standard rules envisage that the calculations of the necessary illuminance in industrial premises be based on a diffuse not direct sunlight.

Natural illumination within industrial buildings can be *lateral*, *skylight* and *mixed*, and is provided through side windows, skylights or both, respectively. The distribution of illuminance depending on the type of natural illumination can be illustrated by the curves in Fig. 36 which are the principal guidelines used for the positioning of the equipment so as to avoid screening or shading of workplaces that are far from light openings.

A criterion used in evaluating natural illumination within buildings is the *daylight factor* (DLF). This factor is the percentage ratio of the illuminance at any point in the building to the illuminance

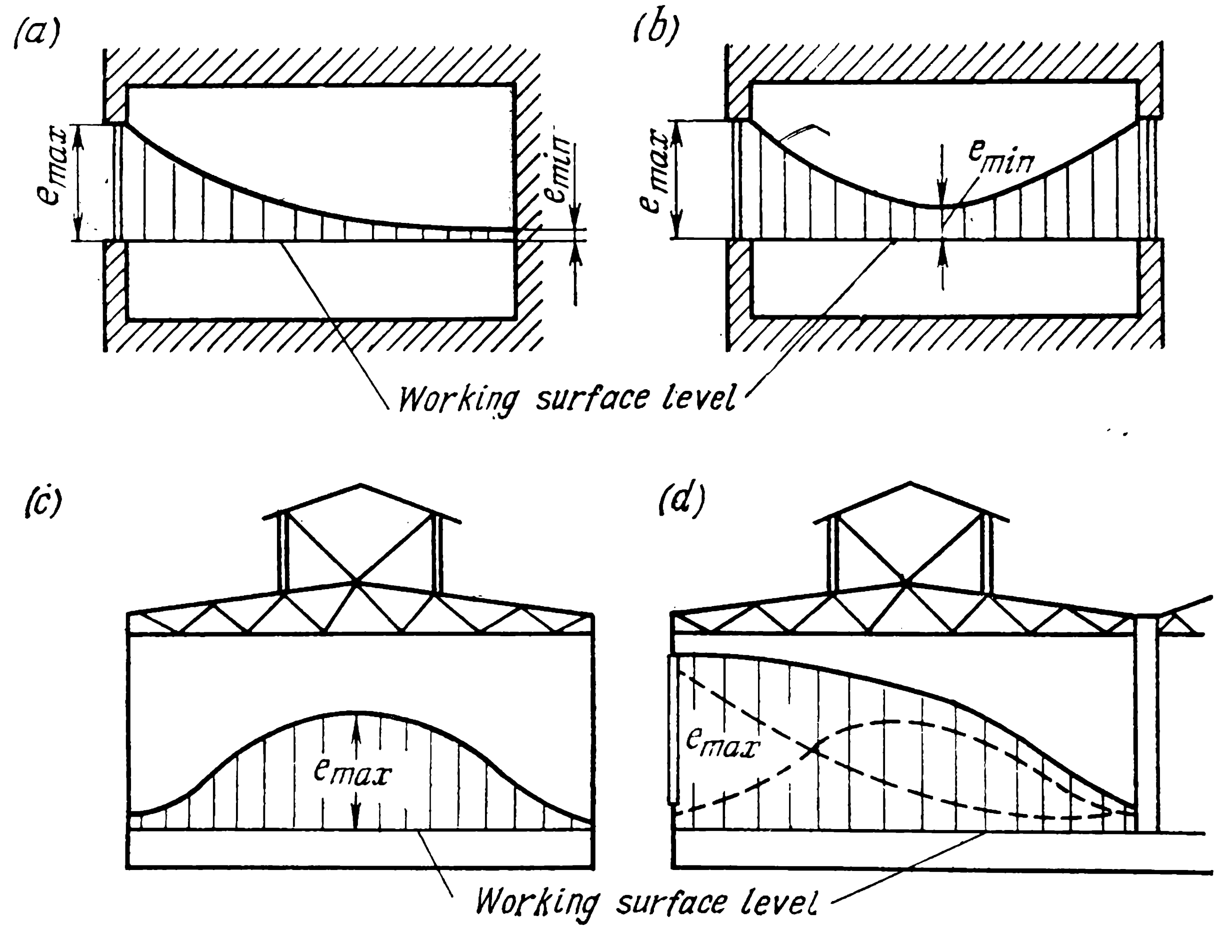

Fig. 36. Schematic distribution of natural light within enclosure depending on position of light openings

(*a*) unilateral, (*b*) bilateral, (*c*) skylight, (*d*) mixed

measured at the same time on a horizontal platform (plane) outside the building when this platform is illuminated by the diffuse light of the whole sky. The symbol *e*:

$$e = \frac{E_{in}}{E_{out}} 100$$

where E_{in} is the illuminance of the point inside the building; and E_{out} is the illuminance of the horizontal platform outside the building.

Table 6

Character of visual task	Size of object to be discerned, mm	Class of visual task	Subclass	Contrast between object and background	Background
Exceptionally difficult	max. 0.15	I	a	Low	Dark
				Low	Semi-dark
			b	Soft	Dark
				Low	Light
			c	Soft	Semi-dark
				High	Dark
				Soft	Light
			d	High	Light
				High	Semi-dark
Very difficult	0.15-0.3	II	a	Low	Dark
				Low	Semi-dark
			b	Soft	Dark
				Low	Light
			c	Soft	Semi-dark
				High	Dark
				Soft	Light
			d	High	Light
				High	Semi-dark
Difficult	0.3-0.5	III	a	Low	Dark
				Low	Semi-dark
			b	Soft	Dark
				Low	Light
			c	Soft	Semi-dark
				High	Dark
				Soft	Light
			d	High	Light
				High	Semi-dark
Normal range of tasks	0.5-1	IV	a	Low	Dark
				Low	Semi-dark
			b	Soft	Dark
				Low	Light
			c	Soft	Semi-dark
				High	Dark
				Soft	Light
			d	High	Light
				High	Semi-dark
Ordinary	1-5	V	a	Low	Dark
				Low	Semi-dark
			b	Soft	Dark
				Low	Light
			c	Soft	Semi-dark
				High	Dark
				Soft	Light
			d	High	Light
				High	Semi-dark
Rough intermittent	min. 5	VI		Not to count	
Simple	—	VII		Not to count	

Table 6 (cont.)

Character of visual task	Size of object to be discerned, mm	Class of visual task	Subclass	Contrast between object and background	Background
Movement and orientation:					
permanent supervision		VIII	a	Not to count	
periodic supervision, permanent presence of people			b	Not to count	
periodic supervision, occasional presence of people			c	Not to count	
In warehouses:					
non-mechanized	—	IX	a	Not to count	
mechanized			b	Not to count	

For the lateral-type illumination the point for measuring the illuminance in the building lies on the line where the vertical plane of the specific section of the building (axis of window opening, etc.) intercepts the horizontal plane 1.0 m above the floor level, and at the most remote distance from the light opening; for the skylight-type natural illumination, this point is on the line where the vertical plane of the specific section of the building intercepts the horizontal plane at a height of 0.8 m above the floor level.

The magnitude of the daylight factor depends on the size and location of the light openings, the extent to which these openings transmit the light, the presence of external objects that have a screening effect, and the reflectivity of the interior surfaces of the room.

In the USSR, natural illumination is standardized. The purpose of industrial buildings and visual tasks to be performed are important factors in establishing illumination standards. By standards all the visual tasks in industry are grouped into nine classes (Table 6). The basic standardized parameter is the DLF which for industrial premises ranges from 0.1 to 10%. For the lateral illumination, the DLF is minimum ($e_{min} = 0$) and for the skylight-type and mixed illumination, the DLF is the average (e_{av}).

Magnitudes of DLF for the mid-European USSR are given in Table 7.

Natural illumination within buildings can be improved by a correct orientation of buildings, by light-colored finishing of rooms, by considering such factors as the depth of the interior space, area of floor, side windows and skylights, screening effect from the neighboring buildings. The influence of these factors on natural lighting

Table 7

Character of visual task	Size of object to be discerned, mm	Class of visual task	Value of DLF, %	
			skylight and mixed illumination	lateral illumination
Exceptionally difficult	max. 0.15	I	10	3.5
Very difficult	0.15-0.3	II	7	2.5
Difficult	0.3-0.5	III	5	2.0
Normal range of tasks	0.5-1	IV	4	1.5
Ordinary	1-5	V	3	1.0
Rough intermittent	min. 5	VI	2	0.5
Simple	—	VII	3	1.0
Movement and orientation:				
permanent	—	VIII	1	0.3
periodic	—		0.7	0.2
In warehouses	—	IX	0.5	0.1

within buildings can be avoided by using correction factors available in the code of practice for the design of industrial buildings.

Depending on the type of natural illumination, the area of light openings (windows and skylights) can be determined by using the following formulas:

for the lateral illumination,

$$S_w = \frac{S_{fl} e_{cal} h_w K}{\tau_0 r_1 100}, \text{ and}$$

for the skylight illumination,

$$S_{sky} = \frac{S_{fl} e_{cal} h_{sky}}{\tau_0 r_2 100}$$

where S_w and S_{sky} are the areas of windows and skylight openings, respectively; S_{fl} is the floor area; e_{cal} is the standard DLF value; and K is the factor to correct for the screening effect from the neighboring structures; τ_0 is the coefficient of light transmission; r_1 and r_2 are the factors to correct for light reflection, for the lateral and skylight types of natural illumination.

The value of e_{cal}, which should take into account the character of the visual task and the climatic illumination factor for the locality of the building, can be calculated by using

$$e_{cal} = emc$$

where m is the climatic illumination factor (with no allowance for direct sunlight) that depends on the geographic locality; c is the coefficient of the climatic sunshine factor (with allowance for direct sunlight).

This value of DLF is accepted as the minimum.

By the climatic illuminance, the territory of the USSR is divided into five light belts (I is the northernmost and V is the southernmost)

Belt	I	II	III	IV	V
Climatic illumination factor m	1.2	1.1	1	0.9	0.8

Climatic sunshine factor c, a dimensionless characteristic ranging from 0.65 to 1, accounts for the climatic light belt and the luminous flux that enters a building during a year through the light openings due to direct sunlight, probability of sunshine, orientation of the building, and design of light openings.

The objective of the calculation of natural lighting is the ratio of the total area of glass-fronted side windows and skylights to the floor area ($S_{w,\ sky}/S_{fl}$). The minimum values of this ratio are given in Table 8.

Table 8

Class of visual task	I	II	III	IV	V	VI
Minimum $S_{w,\ sky}/S_{fl}$	1 : 3...1 : 4	1 : 4...1 : 5	1 : 5...1 : 6	1 : 6...1 : 7	1 : 7...1 : 8	1 : 8...1 : 10

The ratios in Table 8 have been determined under the assumption that the cleaning of windows and whitewashing or painting of walls and ceilings is done regularly, and not less frequently than two times a year and once in three years in rooms where releases of fumes, smoke and dust are insignificant; and not less frequent than four times and once a year, respectively, where such releases are significant. Smutty or sooty glass of the light openings (side windows and skylights) is likely to reduce 5-7 times the illuminance within workrooms.

3.3. ARTIFICIAL ILLUMINATION

Although from the physiological point of view natural illumination is the most favorable kind of illumination for humans, it is sometimes insufficient and resort has to be made to artificial lighting.

In many cases, engineering or economic considerations justify the construction of buildings without any natural illumination. Natural illumination may be not feasible for rooms where a constant temperature and humidity must be maintained, for rooms with

high cleanness requirements and for rooms that require a rigidly specified illumination.

At the turn of the 20th century, electrical illumination became widespread, and is now the main type of artificial illumination. The use of artificial illumination is regulated by standards. The basic quantitative standard characteristic is the illuminance which can range from 5 to 5 000 lux, depending on the purpose of the premises, working conditions, and the type of work to be performed. The existing standards also regulate the qualitative characteristics of artificial illumination: uniform lighting of working surfaces, absence of abrupt changes of illuminance, elimination of direct glare and any sort of visual discomfort or dazzling conditions, favorable conditions of shadowing, and sufficient brightness of all surrounding surfaces including the ceilings and walls.

To satisfy these criteria, a rational illumination of industrial premises requires general illumination of the entire area. The general illumination of the workplaces is often supplemented by local lighting resulting in combined or mixed illumination. The installation of local illumination without general lighting is prohibited.

Incandescent lamps and gas-discharge devices are used as light-sources for artificial illumination. The basic standard characteristics of the electric lamp are the rated voltage, wattage, luminous flux, luminous efficiency and service life.

Incandescent lamps use the ability of a high-melting substance to emit white or red light because of its high temperature, e.g., a glowing electric-lamp filament. The luminous flux depends on the lamp watt consumption and temperature of the filament (tungsten) in a sealed glass bulb filled with an enert gas, such as argon, xenon or krypton, or a mixture of these, which increases the temperature. Incandescent lamps are simple to manufacture and reliable in service. Their disadvantages include low luminous efficiency (3-6 times lower than that of gas-discharge devices), short service life (about 1 000 h) and unfavourable spectral distribution in which the yellow and red regions prevail, compared to daylight, over the blue and violet regions. This produces a distorted visual sensation. Incandescent lamps give much luminance but a nonuniform distribution of the luminous flux. To avoid direct glare and protect the eye from dazzle such lamps are usually shaped. To this end, about half of the luminous flux from the open incandescent lamp is not used for the lighting of the working surfaces and therefore the use of incandescent lamps is limited mostly to lighting fixtures.

The electric-discharge lamp is a form of electric device in which the light is obtained from an electric discharge between two electrodes in an evacuated glass tube. Commonly called a gas-discharge lamp. Gas-discharge lamps are economical, have a high luminous efficiency and a long service life (8 000-14 000 h) and in many cases

have replaced the incandescent lamps. Gas-discharge devices provide illumination of a much better quality as the spectrum of their luminous radiation is much closer to that of daylight.

These lamps are, however, disadvantageous in that they require a relatively complicated switching circuit and specialized appliances for starting. Their enabling voltage is higher than the mains voltage and therefore it takes time to start-up the lamp. These lamps can produce a stroboscopic effect on the visual sensation (rapidly moving or rotating objects may seem to be immobile). The phenomenon occurs due to the pulsation of luminous flux, and may cause radiointerference.

For most manufacturing process stroboscopic effect is undesirable. It can be avoided by using the switching circuits designed specifically for the purpose. The circuits require specialized start-up and adjustment equipment that include capacitors to increase the illumination unit power factor and eliminate radiointerference.

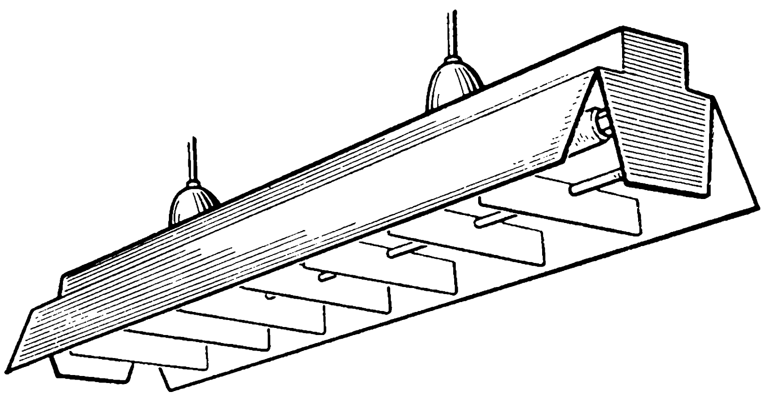

Fig. 37 A fluorescent lamp

Of the gas-discharge devices it is *fluorescent lamp* (Fig. 37) that produces the highest quality of illumination and can successfully imitate natural illumination. It is a mercury-vapor electric-discharge lamp having the inside of the glass tube coated with a fluorescent material (luminophore, i.e. a substance which emits light at room temperature), so that ultra-violet radiation from the discharge is converted to light of an acceptable color. The industry manufactures fluorescent lamps which, according to the kind of luminous radiation, are distinguished into the following types: white light (FW), hot white light (FHW), cold white light (FCW), daylight (FDL), and corrected-image light (FCI). In addition to the principle types, various other fluorescent lamps are produced too for a variety of local illumination purposes.

As a source of light, fluorescent lamps should preferably be used for rooms with high illumination requirements, for the performance of difficult visual tasks that involve much visual strain, or tasks that require differentiation of various tints of color, and also for

rooms where natural illumination is insufficient or unprovided. If the visual task demands a correct distinction between colors or color tints the FCI lamps are preferable. Lighting installations for general illumination should use the FDL lamps which have a high luminous efficiency and negligible fluctuations of the luminous flux. For local illumination, fixtures using the FCL or FDL lamps are most preferable.

Fluorescent lamps are sensitive to the air temperature which optimum range is 20-25°C. Lowering of temperature causes a reduction in the luminous flux. Starting a fluorescent lamp at temperatures close to 0°C is difficult.

High-pressure mercury discharge (HPM) lamp is a form of electric-discharge lamp in which discharge takes place through mercury vapor. Also called mercury-vapor lamp. A common type consists of a quartz tube containing a measured quantity of mercury vapor housed in a bulb or tube of refractory glass the inside wall of which is coated with luminophore. The ultra-violet radiation from the discharge in the quartz tube causes the luminophore to emit light. The luminous efficiency of the mercury-vapor lamp is about the same as of the fluorescent lamp. The service life is about 5 000 h. Unlike the fluorescent lamps which are low-pressure devices, the high-pressure mercury discharge lamps are independent of the ambient temperature. The lamps are lighted by way of a specialized starting device that also stabilizes their operation.

The present-day *luminaire* is a complete lighting unit consisting of lighting fixtures and one or more light sources. The accessories distribute the light flux in the surrounding space and protect the eye from dazzle produced by the light source. In addition, the lighting fixtures permit changes in such characteristics of the light flux as intensity and spectral distribution. Other purposes of lighting fixtures include the mounting of the light source, the connection of the light source to the supply system, the protection of the light source from mechanical damage, and from the effects of the surroundings. The most important part of a lighting fixture is the optical system that effects the distribution and conversion of the light flux. Luminaires with gas-discharge light sources include devices for starting the lamp and for stabilizing its operation.

The principal criteria for evaluating the operation of a luminaire are the character of the light distribution, the magnitudes of the cut-off angles (the angles determining the zone in which the observer's eye is protected from the direct action of the light source), the luminance of the surfaces within the field of vision, and the efficiency of the luminaire.

Luminaires can be classified according to their functional purposes into luminaires for general lighting and luminaires for local lighting. Those for general lighting are used to produce the required

illuminance of the working surface of a room and to provide a favourable distribution of brightness. Those for local illumination are designed primarily to provide increased illuminance of individual areas of the working surface. When a classification is made according to the method of mounting, the following types can be distinguished: suspended, ceiling, built-in, built-on, wall, table, floor, crown, overhanging, hand, head luminaires or lamps. With respect to the degree

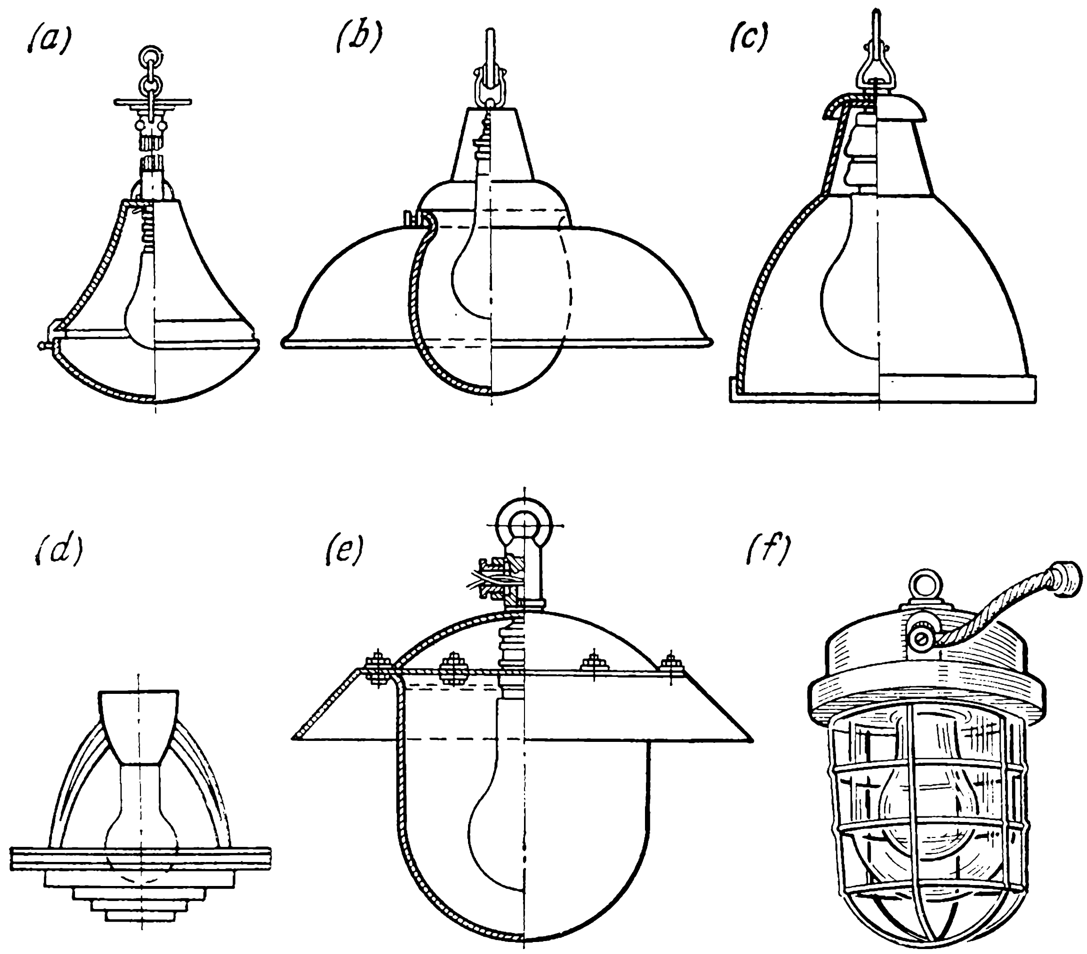

Fig. 38. Basic types of lighting fixtures (luminaires)
(*a*) and (*d*) diffuse light; (*b*), (*c*) direct light; (*e*) dust and water proof; (*f*) explosion-proof

of protection from dust and moisture, the following types are known: open, covered, completely or partially dustproof (Fig. 38*e*), unprotected from water, drop-proof, spray-proof, splash-proof, watertight (Fig. 38*e*) and airtight. Special explosion-proof luminaires are also available (Fig. 38*f*). When classed by the uniformity of the light flux distribution, distinction is made between luminaires of direct light, predominantly direct light (Fig. 38*b*, *c*), diffuse light (Fig. 38*a*, *d*), incident light, predominantly incident light (Fig. 39). Such subdivision is based on the ratio of the light flux emitted into lower spheres to the light flux radiated by the luminaire.

Direct-light luminaires are preferably used in rooms where the reflectivity of walls and ceilings are low, and the predominantly direct light luminaires where the reflectivity of the surrounding surfaces is high. In rooms with high ceilings, a rational illumination

can be achieved by using luminaires that give a concentrated light flux (projectors) directed downward onto the working plane. In low-ceiling but spacious enclosures it is preferable to use luminaires with a wider range of the light flux distribution.

The basic criterion for choosing the proper type of a luminaire is the environment. No special requirements exist for luminaires used under normal working environment. For highly humid conditions or in rooms with excess moisture releases, the lamp-holder body should be made of water-proof insulating materials. Special requirements are placed on luminaires for extremely wet conditions, for rooms with a chemically active or explosion hazardous atmosphere.

Luminaires for local lighting are designed particularly to increase the illumination of certain areas of the working surface. Hinged-bracket mounting permits any desirable directional adjustment of

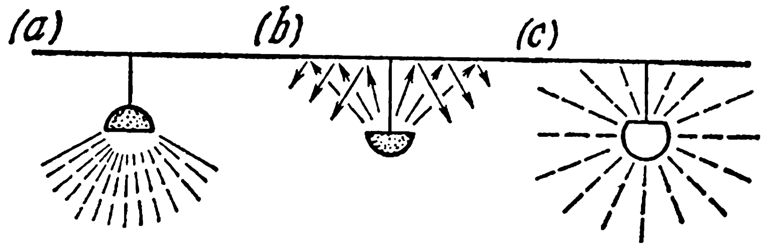

Fig. 39. Light from luminaires can be (a) direct; (b) reflected; (c) diffuse

the light flux. Because such luminaires are positioned in close vicinity of the worker it is desirable that the cut-off angle be not less than 30°, and not less than 10° where the luminaire light source is at the viewer's eye level, to exclude direct glare.

With mixed lighting the illuminance of the working surface from general illumination should constitute not less than 10% of the designed.

Emergency lighting is often provided in addition to the normal operational lighting to make it possible to continue operations temporarily or to ensure escape for the people during failure of the operational illumination. Emergency illumination should have a separate power supply unit and a device for starting it automatically as soon as failure of the light occurs.

In plants, factories and other undertakings of manufacturing industries, emergency lighting should be provided under the following circumstances:

(1) to continue operations in workrooms where failure of the normal lighting may be conducive to accidents (fire, explosion or poisoning) due to inadequate working conditions, or where failure of the normal illumination may cause undesirable changes in the manufacturing process. The standard minimum illuminance that emergency lighting should provide inside the building is not less

than 5% of the general lighting illuminance alone, and should be not less than 2 lx on the floor and 1 lx on the open grounds;

(2) to evacuate people from workrooms with more than 50 occupants if failure of the operational lighting may be conducive to accidents from machines and equipment, or the room has places that are dangerous for the passage of people;

(3) at places, such as gangways, staircases, traffic and walksides, where a risk of stumbling or falling exists, and near exits which have to be used in emergencies, at escape-ways from buildings with more than 50 occupants;

(4) in separate enclosures where more than 100 people may reside at one time (lecture-rooms, conference halls, etc.).

The standard minimum of illuminance that emergency lighting should provide if normal light fails is not less than 0.5 lx measured on the floor area, and not less than 0.2 lx, on the open ground.

3.4. STANDARD REQUIREMENTS FOR ARTIFICIAL ILLUMINATION

As was mentioned earlier, the basic quantitative characteristics of artificial illumination is the illuminance, which is standardized. Because gas-discharge lamps are more economical, the limits of the illuminance, by the standard, are higher than for incandescent lamps. This helps considerably improve illumination in the workrooms with the same power input.

Table 9 gives standard limits of illuminance for various classes and sub-classes of visual tasks. In the parentheses, it shows the illuminance limits rated for the buildings and building quarters where natural illumination is insufficient. The first six classes require increased levels of illuminance in the building without, or with insufficient, natural lighting. The requirement is mandatory for all other visual task classes only in buildings where natural illumination is not provided, whatever.

The standard provides for higher levels of illuminance within buildings without natural lighting or where it is insufficient. But the improvement should be achieved exclusively through luminaires for general lighting no matter the adopted system of illumination (general or mixed). The total illuminance produced by the luminaires of both general and local lighting is assumed similar to that in the building where natural illumination is quite sufficient. The standard specifies the illuminance limits separately for the gas-discharge light sources and incandescent lamps, and also for such circumstances wherein general illumination is achieved by way of gas-discharge light sources, and local lighting, with incandescent lamps. The standard fixes different limits of illuminance for lighting installations that use gas-discharge light sources and incandescent

Table 9

Class of visual task	Sub-class	Gas-discharge devices: mixed illumination, lx: general and local	Gas-discharge devices: mixed illumination, lx: general	Gas-discharge devices: general lighting	Incandescent lamps: mixed illumination, lx: general and local	Incandescent lamps: mixed illumination, lx: general	Incandescent lamps: general lighting	Mixed illumination: gas-discharge lamps (general) and incandescent lamps (local, lx): general and local	Mixed illumination: gas-discharge lamps (general) and incandescent lamps (local, lx): general
I	a	5 000	500 (750)	1 500	4 000	100 (300)	300	4 000	400 (750)
	b	4 000	400 (750)	1 250	3 000	100 (300)	300	3 000	300 (600)
	c	3 000	300 (600)	1 000	2 000	100 (300)	300	2 000	200 (400)
	d	1 500	150 (300)	400 (500)	1 250	100 (300)	300	1 250	150 (300)
II	a	4 000	400 (750)	1 250	3 000	100 (300)	300	3 000	300 (600)
	b	3 000	300 (600)	750	2 500	100 (300)	300	2 500	— (500)
	c	2 000	200 (400)	500 (600)	1 500	100 (300)	300	1 500	150 (300)
	d	1 000	150 (200)	300 (400)	750	75 (150)	200 (300)	750	150 (200)
III	a	2 000	200 (400)	500 (600)	1 500	100 (300)	300	1 500	150 (300)
	b	1 000	150 (200)	300 (400)	750	75 (150)	200 (300)	750	150 (200)
	c	750	150 (200)	300 (400)	600	75 (150)	200 (300)	600	150 (200)
	d	400	150 (200)	200 (300)	400	50 (100)	150 (200)	400	150 (200)
IV	a	750	150 (200)	300 (400)	600	75 (150)	200 (300)	600	150 (200)
	b	500	150 (200)	200 (300)	500	50 (100)	150 (200)	500	150 (200)
	c	400	150 (200)	150 (200)	400	50 (100)	100 (150)	400	150 (200)
	d	300	150 (200)	150 (200)	300	50 (100)	100 (150)	300	150 (200)
V	a	300	150 (200)	200 (300)	300	50 (100)	150 (200)	300	150 (200)
	b	200	150 (200)	150 (200)	200	50 (100)	100 (150)	200	—
	c	—	— —	100 (200)	—	—	50 (100)	—	—
	d	—	— —	100 (200)	—	—	50 (100)	—	—
VI	—	—	— —	100 (200)	—	—	50 (100)	—	—
VII	—	—	— —	200 (300)	—	—	150 (200)	—	—
VIII	a	—	— —	75 (200)	—	—	30 (100)	—	—
	b	—	— —	50 (200)	—	—	20 (100)	—	—
	c	—	— —	50	—	—	5	—	—
IX	a	—	— —	50	—	—	20	—	—
	b	—	— —	50	—	—	5	—	—

lamps. The difference is set in favor of the gas-discharge lamp fixtures as the most economical and efficient. The use of the incandescent light sources is thus limited to the cases where gas-discharge lamps are impracticable.

The standard provides for increased levels of illuminance in rooms where natural lighting is insufficient and with the lateral-type illumination constitutes less than 80%, while with the skylight-type lighting, less than 60% of the standard required quantity. The levels of illuminance are reduced for rooms whose occupation is limited to short-time intervals. For maintenance and adjustment to be carried out on fully automatic production lines additional luminaires for general lighting (both stationary and portable) are provided to increase the illuminance, which normally is rated according to the visual tasks under Class VIII.

Luminaires should be mounted rigidly in place to exclude swinging by air currents. When in service, the light emitted from the luminaires is likely to dim out due to dust and soot lodging on the surfaces of the lighting fixtures. When rating the illuminance levels, allowance for such possibility should be made by using a correction factor which can take on any value from 1.3 to 1.7 for incandescent lamps, and from 1.5 to 2.0, for gas-discharge devices, depending on the content of dust, smoke and soot, and the dust color.

3.5. CALCULATION OF ARTIFICIAL ILLUMINATION

Customarily, calculations of artificial lighting installations in industrial buildings are performed by the following four methods, namely, the light-source point method, the wattage method (using tables of power densities), the graphical method, and the light-flux utilization factor method.

The method of light-source points is applied for calculating illumination fixtures in which light sources are localized. The method permits determination of the illuminance of inclined planes and the checking of the uniformity of general illumination (exclusive of the reflected luminous flux).

The wattage method is the simplest and hence the least precise among all other methods used in illumination engineering. Used generally for rough calculations, it provides the possibility of determining the necessary wattage of each light source, in watt, to ensure the required illuminance specified by the standard, from the following expression:

$$P_l = PS/N$$

where P_l is the wattage of a light source, W; P is the power density, or specific power, W/m^2; S is the room area, m^2; and N is the number of light sources (lamps) in the lighting fixture.

Power density depends on the value of standard illuminance, the area and height of room, the type and location of the luminaire and the marginal factor, and can vary within a wide range of values, e.g. with illuminance up to 200 lx, from 8 to 28 W/m^2. The values are available from the appropriate tables.

The graphical method of Prof. Trukhanov is the most accurate when calculating lighting installations in which light sources are projectors. The method implies use of specialized nomograms.

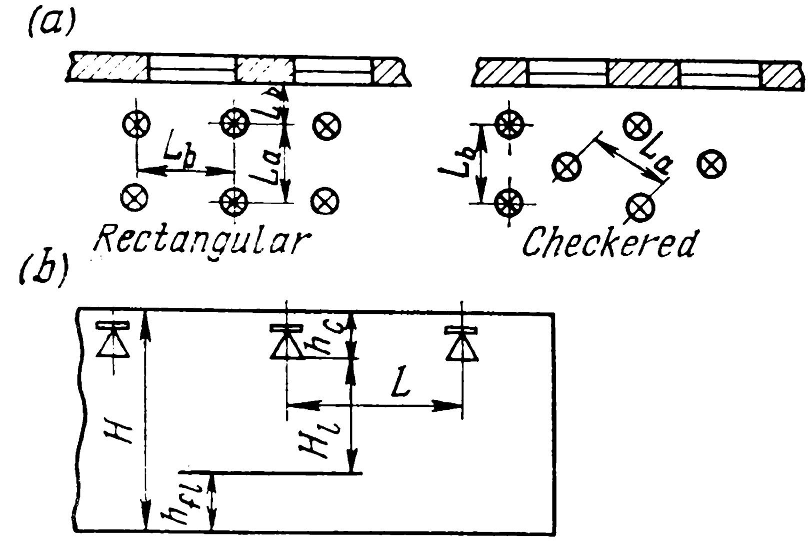

Fig. 40. Luminaire arrangement patterns in industrial premise
(a) in plan; (b) sectional view on the illuminated surface from the height of a light source

The method of light flux utilization factor is the most applicable to the calculation of general uniform lighting in industrial-type buildings. The method permits taking into account of both the direct light from the luminaire and light reflected from the walls and the ceiling, by way of the following formula:

$$F = ESKz/\eta n$$

where E is the illuminance, lx; S is the area of enclosure, m^2; K is the factor to correct for the luminary's soiling (from Table 10); z is the lighting nonuniformity coefficient; η is the light flux utilization factor of a lighting fixture; n is the number of light sources (lamps).

The calculation procedure, according to the method, is as follows. We first choose the pattern of the luminaire distribution which may be either symmetrical or localized. The first pattern implies that the luminaires are distributed symmetrically either crosswise or lengthwise the rectangular-shaped enclosure, or in a checkered manner (Fig. 40). The symmetrical method gives a uniform lighting of the whole area including equipment, machine-tools, workplaces and passages, but demands a higher power requirement. The localized pattern of distributing lighting fixtures is tied up more to the physical positions of the equipment, machine-tools, control boards and

panels, and other workplaces. Such arrangement minimizes the power requirement, and is suitable for departments where positioning of equipment is asymmetrical.

We then determine the ratio of the distance L between the luminaires to their height above the surfaces to be illuminated. The ratio L/H_l, depending on the type of luminaire, may equal 1.4-2.0 for the rectangular arrangement, and 1.7-2.5, for the checkered arrangement.

The height of the luminaire above the surface to be illuminated is found as

$$H_l = H - h_c - h_{fl}$$

where H is the total height of the enclosure, m; h_c is the height from ceiling to the lower edge of luminaire, m; h_{fl} is the height from the floor to the surface being illuminated, m.

To minimize dazzling effect from luminaires for general illumination, their height from the floor level should be not less than 2.5-4 m for electric lamps with a wattage up to 200 W, and not less than 3-6 m for lamps of a larger power consumption.

The necessary number of light sources (lamps) $n = S/L^2$ at $L_a = L_b$, where L_a and L_b are the length and width of enclosure, respectively, m.

Next, we determine the enclosure index:

$$i = \frac{ab}{H_l(a+b)}$$

Using the enclosure index and reflection coefficients for the walls and ceilings we find from the appropriate tables the luminous flux utilization factor η of a lighting fixture. The light flux utilization factor is the ratio of the light flux that strikes the unit surface to the light flux emitted by all light sources. The factor depends on the efficiency and the luminous intensity distribution curve of the luminaire, its height H_l, enclosure index i, reflection coefficient of the walls ρ_w and ceiling ρ_c.

At $\rho_w = \rho_c = 0.7$, the light flux utilization factor η depending on the enclosure index will take on the following values:

i	0.5	1	2	3	4	5
η	0.22	0.37	0.48	0.54	0.59	0.61

Adequate lighting of industrial premises and workplaces depends not only on the correct choice of position for luminaires, type of luminaire, wattage of light sources, but also on the color of the surrounding surfaces. The ceiling should preferably be colored white and the walls and equipment surfaces made of or painted with light-colored materials.

7—01564

The illumination nonuniformity coefficient z is then determined as the ratio of the mean illuminance E_m to the minimum illuminance E_{min}. It depends on the ratio L/H, position and type of luminaire, and varies from 1.1 to 1.5.

Table 10

Item	Objects to be illuminated	Luminaire with	
		gas-discharge lamps	incandescent lamps
1	Industrial premises in which the air contains 10 mg/m³ and more, smoke and		
	(a) dark-colored dust	2.0	1.7
	(b) light-colored dust	1.8	1.5
2	Industrial premises in which the air contains from 5 to 10 mg/m³ smoke, fumes, and		
	(a) dark-colored dust	1.8	1.5
	(b) light-colored dust	1.6	1.4
3	Industrial premises in which the air contains not more than 5 mg/m³ dust, smoke and fumes. Auxiliary premises with normal atmosphere and premises in public and communal buildings	1.5	1.3
4	Industrial areas (grounds) in which the air contains		
	(a) more than 5 mg/m³ smoke, fumes and dust	1.5	1.3
	(b) 5 mg/m³ and less, smoke, fumes and dust	1.5	1.3

Note. Marginal coefficients are established under assumption that luminaires are regularly cleaned min. 2 times a month in premises under item 1; min. once a month in premises under item 2; min. once in three months in premises under item 3 and 4a; and min. once in six months in premises under item 4b.

The marginal factor used to correct for illumination dim-out during service is found from Table 10.

Having obtained all the initial quantities we can determine the luminous flux for one light source and, using Table 11, the required wattage of a lamp.

Instrumentation. As is not unknown, illumination, that is, the quantity of light or luminous flux falling on a unit area of a surface, is inversely proportional to the square distance of the surface from the light source. The unit of illumination is the lux (also known as the meter-candle) defined as the illumination produced by light from a source of unit intensity falling normally on a surface at

a distance of one meter. A common instrument for measuring the intensity of illumination in industrial buildings and at workplaces is the photometer. Most photometers employ the principle that,

Table 11

Incandescent lamps					Fluorescent lamps		
	127 V		220 V			220 V	
Type and wattage	light flux, lm	luminous efficiency, lm/W	light flux, lm	luminous efficiency, lm/W	Type and wattage	light flux, lm	luminous efficiency, lm/W
IV-15	135	9.0	105	7.0	FDCI-20	820	41.0
IV-25	260	10.4	220	8.8	FDL-20	920	46.0
IBS-40	490	12.2	400	10.0	FBS-20	1 180	59.0
IBSK$_r$-40	520	13.0	460	11.5	FDLCI-30	1 450	48.2
IBS-60	820	13.7	715	11.9	FDL-30	1 640	54.5
IBSK$_r$-100	1 630	16.3	1 450	14.5	FWL-30	2 100	70.0
IG-150	2 300	15.3	2 000	13.3	FWLCI-40	2 100	52.5
IG-200	3 200	16.0	2 800	14.0	FDL-40	2 340	58.5
IG-300	4 950	16.5	4 600	15.4	FWL-40	3 000	75.0
IG-500	9 100	18.2	8 300	16.6	FDLCI-80	3 560	44.5
IG-750	—	—	13 100	17.5	FDL-80	4 070	50.8
IG-1 000	19 500	19.5	18 600	18.6	FWL-80	5 220	65.3

Note. Designations of lamps include characters of which the first stand for the type of light source: I – incandescent and F – fluorescent; the following characters, for the design features, incandescent lamps: K$_r$ – crypton, V – vacuum, BS – bispiral, G – gas-discharge or filled; and kind of light, fluorescent: DL – daylight, CI – improved color image, and WL – white light.

if equal illumination is produced on similar surfaces illuminated normally by two light sources, the ratio of their intensities equals the square of the ratio of their distances from the surfaces. Photo-electric photometers are devices in which the light is measured by the current from a photo-electric cell. One such instrument is the luxmeter, a name given to portable photometers which operate on the contrast principle and employ a variable aperture (Fig. 41). The luxmeter incorporates a photo-electric cell, an essential device to indicate an intensity of illumination on a scale of a milliammeter calibrated in lux. To take a measurement at a given point it is enough to expose the photo-cell to the light flux in the plane parallel to the workplace plane and take the reading on the scale. The scale is graduated for the spectral composition of incandescent lamps.

The readings can be easily calculated for the illumination intensities produced by gas-filled devices by using a correction coefficient which for the FWL lamps is equal to 1.15; for FDL lamps, 0.88; for HPM lamps, 1.2, and for natural light 0.8.

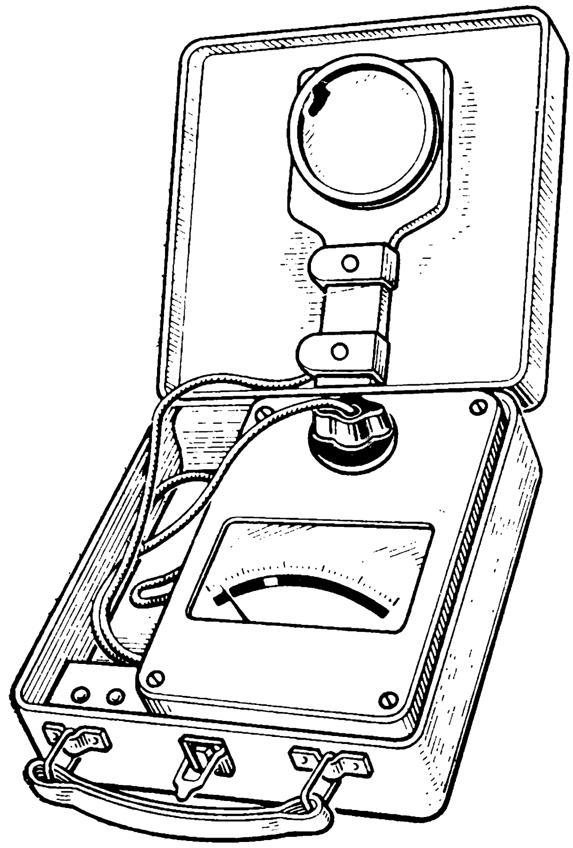

Fig. 41. Portable lux(o)meter

3.6. ULTRA-VIOLET IRRADIATION

The therapeutic effect of sunlight or optical radiation including infrared, visible and ultra-violet (UV) radiation has long been recognized, and is known as phototherapy which is a branch of physical therapy.

Ultra-violet radiation, both local and general, is used to compensate for an UV radiation insufficiency and to increase resistance to various infections (e.g., influenza). Low doses of UV irradiation has a favorable biological effect on man as absorbed by the skin. It causes chemical changes in the molecules of biopolymers, facilitates the formation of the group D vitamins in the human body and improves its immunobiological properties. The UV radiation is the invisible electromagnetic radiation that occupies a spectral region between the visible and X-ray radiations within the range of wavelengths from 400 to 10 nm. The UV region of the spectrum is conditionally divided into the near (longwave) sub-region (400-200 nm) and the far (vacuum) sub-region (200-10 nm). From the therapeutic point of view the near sub-region of the UV radiation is most important.

Industrial premises in which natural illumination is biologically insufficient (DLF $< 0.1\%$) must be equipped with UV radiation sources (sunlamps). For this purpose thermal and luminescent artificial light sources are used. Thermal sources include incandescent lamps, luminescent sources in which radiation is achieved by electrical, chemical and other processes, mercury-vapor lamps, luminescent sunlamps (sometimes called erythematous lamps), and arc bactericidal lamps.

Sunlamps are installed either directly in a workshop or workroom to provide the necessary doses of the UV radiation for the occupants during the working day (shift) using a low level UV irradiation, or

a specialized room used for a group TuV irradiation treatment (called the photarium). Luminous energy effect on man is determined by its intensity (luminous efficiency of the source and distance to the irradiated surface), by the duration of irradiation, and the penetration depth of electromagnetic waves. Sunlight treatment in phototherapy rooms is short (3-5 min) and is effected by increased levels of irradiation.

With respect to the biological effect (bactericidal, erythematous, antirachitis, and sun tan), the longer wave UV region of the light spectrum can be divided into several sub-regions in which emissions may arbitrarily be called after the effect they produce. For the present purpose, we consider only the so-called erythematous subregion because the quantity of erythematous radiation has been adopted as a standard measure of UV irradiation, i.e. UV radiation dose.

Erythema, that is, redness of the skin, may appear a few minutes after irradiation (from two to eight hours after exposure to UV ray). The irradiated area acquires a tan in 3-4 days.

The value of the erythematous radiation is analogous to illumination and is determined by the surface density of the erythematous flux. The unit of erythematous flux density is er, and milli-er or mer. Er is equivalent to a power of 1 W of a flux of monochromatic radiation of a wavelength of 237 nm. The unit measure of UV radiation is milli-er per square meter (mer/m^2). To avoid excessive irradiation the standard sets the lower and upper limits for irradiation dose. The maximum dose is 7.5 mer/m^2 and the minimum, 1.5 mer/m^2. The intensity of irradiation is measured by a device known as the UV light meter.

Phototherapy is contraindicated in treating the active form of tuberculosis, neoplasms, pronounced heart diseases, the second and third stage of hypertension, acute exhaustion, increased thyroid function, renal diseases and insufficiency, and photopathy (a diseased condition caused by light). It is then advisable that the workers prior to phototherapeutical treatment be examined by medical specialists.

CHAPTER 4

Industrial Vibration: Health Hazards and Their Prevention

The increasing power, crowding of machinery and speed of the working tools employed on an ever greater scale in the present-day manufacturing industries have made dynamic balancing of rotational and translational masses more difficult. A mechanical system may well be in static balance and satisfactorily pass a balance test. But when this system rotates the centrifugal forces, for example, of two weights not being in the same plane perpendicular to the axis of rotation, create a couple acting on the shaft. That couple rotates with the shaft and produces shaking forces at the journals, noise and vibration in the foundation. This adds more to the occupational hazards in the working environment, now due to noise and vibration.

From the physical point of view there is no principal difference between noise and vibration. It is the apperception that matters — vibration is perceived by the vestibular apparatus and taction, and noise, by hearing.

Harmful effects from vibration increase with the speed of machines and mechanisms as the mechanical energy of oscillatory motion is proportional to the squared frequency (or speed of the rotating shaft of machine).

4.1. VIBRATION: CAUSES AND HAZARDS

Vibration commonly refers to a to-and-fro motion; its meaning is often broadened to include any periodic physical process, such, for example, as a cyclic variation in elastic or magnetic field intensity. When an elastic body is deformed and released, it is in general set into oscillation such that the displacement of any particle from its equilibrium position is a more or less complicated harmonic function of the time. Thus, vibration is mechanical oscillations of elastic bodies or systems capable of vibration.

An oscillation is one complete cycle of vibratory or periodic motion, for example, the whole succession of states that takes place before the motion begins to repeat itself with the same velocity (magni-

tude and direction). The time of one oscillation is called the period and the number of oscillations per second (the reciprocal of the period), the frequency. The definition cannot be applied strictly to nonperiodic motions for which the period is usually taken as the time between successive zeros of the displacement. Oscillations that continue in a system after the applied force has been removed are called free or natural oscillations. An oscillation in which there is resistance to the motion is called the damped oscillation. The presence of the resistance leads to a continuous dissipation of the total mechanical energy of motion. The oscillation which results when an external force is applied to a system capable of oscillating is known as the forced oscillation, and the force, the driving or oscillating force.

Of special interest in forced oscillation is the phenomenon of resonance. Velocity resonance is a state of maximum velocity and occurs when the frequency of the driving force has the value $v_0 = 1/2\pi\sqrt{f/m}$; v_0 is called the resonance frequency. Amplitude resonance is a state of maximum displacement and occurs when the frequency of the driving force has the value $v_1 = 1/2\pi\sqrt{f/m - R^2/4m^2}$. When the damping is small, the resonance frequency amplitude v_1 and the free oscillation frequency become approximately the same. At the resonance frequency v_0, the force and velocity are exactly in phase while the force and displacement are 90° out of phase. The word resonance in general usage means amplitude resonance.

Vibration becomes very great when amplitude resonance occurs, that is, when the frequency of the external periodic driving force synchronizes with the natural frequency of the oscillator (machine, apparatus). This leads to excessive vibration amplitudes, may result in failure of the machine, equipment or structure, and may be conducive to accidents.

Vibration is characterized by three parameters, namely, the amplitude of displacement, oscillatory velocity, and acceleration. These parameters are time-dependent and the dependences for displacement (amplitude), velocity and acceleration can be written as $a = \varphi(t)$; $v = \varphi(t)$, and $\omega = \varphi(t)$, respectively. These complex dependences fully describe the oscillatory process. The oscillatory motion is specific in that the magnitudes of the displacement, velocity and acceleration always vary within a limited time interval. It is therefore possible to characterize vibration for a given time interval by the root mean square value of one of these parameters. For practical purposes, two parameters are used, namely the amplitude of displacement (mm), and velocity (m/s; mm/s). The velocity levels can be expressed in logarithmic units

$$L_v = 20 \log v/v_0$$

where v is the oscillatory velocity at the point of measurement, m/s; and v_0 is the threshold velocity equal to 5×10^{-8} m/s.

The effect of vibration on the human body varies depending on whether the whole body (general vibration), or part of it (local vibration) is involved. A combined action of the general and local vibration on the body can also be observed. General vibration from the jolting of the floor or operating platform or the operator's seat affects the whole body. Local vibration from the operation of hand tools, drills, etc., affects mostly the hands of the operator.

Depending on the frequency, intensity and duration of vibration its effect may be limited to a sensation of shaking (pallesthesia) or it may lead to changes in the nervous, cardio-vascular and support-and-motor systems. The internal organs and other separate parts of the body may be considered as oscillatory systems with various concentrated masses, and connected via elastic elements. The natural oscillation frequency of most of the internal systems of the human body varies between 6 and 9 Hz. The biological effect of the superposed vibration therefore depends on its frequency: frequencies up to 25 Hz are still perceived as separate jolts and cause osteoarticular changes; frequencies from 50 to 250 Hz affect the nervous system and cause vascular reactions (spasms) and vibration sickness. External vibration at frequencies equal to the natural frequencies of a body vibrator may result in resonance oscillations and cause displacement and serious mechanical damage. Local vibration may interrupt blood supply to the blood vessels in the hands and arms and may cause loss of sensitivity of the skin, salt deposition, ossification of tendons in hand and finger muscles, and lead to deformation and articular immobilization.

The human body is very sensitive to vertical jolts when a person stands on a vibrating surface and is subjected to jolts affecting the body from feet to head. Fatigue, cold and strain caused by incorrect working posture lessens the body's tolerance to vibration. A prolonged effect on the body of a local or general vibration, or both, may cause an occupational disease known as the vibration sickness[1].

Vibration sickness develops gradually and for a long time does not affect the ability to work. It manifests itself by pains and weakness in the extremities and by increased sensitivity to chilling; subsequently there are many cramps and whitening of the fingers (especially in the cold). Skin sensitivity is reduced and changes are observed in the blood vessels of the extremities. These changes appear against a background of functional disorders of the nervous system (rapid fatigue, irritability, headaches and dizziness).

---

[1] It was described by the Italian physician G. Loriga in 1911, although the first attempts to describe it were made as early as the 19th century by the Russian physicians A.N. Nikitin and F.F. Erisman.—*Translator's note.*

As vibration sickness progresses, there appear disruptions of the cardiovascular activity and of internal secretion, disturbance of metabolic processes, and so on.

Prevention consists of careful occupational screening for jobs, constant supervision by physicians, and strict observance of protective measures for workers. Treatment includes vasodilators and ganglionic blocks, vitamines, physical therapy, therapeutic gymnastics and health-resort treatment.

In engineering (machines, mechanisms, installations, structures, etc.) both useful and harmful vibrations exist. Useful vibration is caused intentionally by vibrators and is used in construction, road-buildings, and in other machines, and for performing various technical operations. Harmful vibration which arises during movement of means of transportation, in the operation of motors, turbines and other machines, sometimes leads to disruption of work schedules and even to destruction of apparatus. It reduces the efficiency of machines causing rapid wear and necessity of frequent repairs and maintenance. Propagating in the surrounding media, vibration leads to the destruction of other machines and equipment, disrupts processes and distorts readings of instruments and other measuring devices.

4.2. MAXIMUM PERMISSIBLE LIMITS OF VIBRATION

General and local vibration affect the body differently and therefore the national standard sets different maximum permissible limits for each type of vibration. The standardized parameter of general vibration is the root mean square oscillatory velocities measured in the octave[1] bands of frequencies or displacement amplitudes induced during the operation of equipment (machines, tools, fans, etc.) and transferred to the workplaces (floor, operating deck, seat, etc.) in the production areas. The standard values of these parameters provided by the hygienic regulations do not apply to the moving transportation means, self-propelled vehicles, etc. The maximum permissible limits of the vibration parameters (Table 12) apply specifically to the permanent workplaces within the production quarters and are calculated for the 8 h exposure to vibration.

Depending on the duration of the exposure to vibration, the tabulated maximum permissible limits can be raised by a factor of 1.4 (3 db) for an exposure of less than 4 h; by a factor of 2 for less than 2 h exposure; and by a factor of 3, for an exposure of less than 1 h

[1] Octave is the interval between two sounds having a basic frequency ratio of two. By extension, the octave is the interval between any two frequencies having the ratio 2:1. The interval, in octaves, between any two frequencies is the logarithm to the base two of the frequency ratio.—*Translator's note.*

Table 12

Geometric mean of octave band frequency, Hz	Oscillatory velocity safe limit		Geometric mean of octave band frequency, Hz	Oscillatory velocity safe limit	
	effective value, mm/s	pressure level of effective value, db		effective value, mm/s	pressure level of effective value, db
2	11.2	107	16	2	92
4	5	100	31.5	2	92
8	2	92	63	2	92

during the whole workday. The length of exposure to vibration should be proved by calculation or technical specifications.

For hand tools, the standard provides maximum permissible limits of oscillatory velocities or their pressure levels measured in the octave-band frequency at points of contact with the hand of the worker. It also specifies the force of the hand pressure feed, mass of the tool or tool parts that the operator holds during the operation.

Table 13

Geometric mean of octave band frequency, Hz	Octave band cut-off frequencies, Hz		Maximum permissible limits of velocity	
	lower	upper	effective value, m/s	pressure level of effective value, db
8	5.6	11.2	5.00×10^{-2}	120
16	11.2	22.4	5.00×10^{-2}	120
31.5	22.4	45	3.50×10^{-2}	117
63	45	90	2.50×10^{-2}	114
125	90	180	1.80×10^{-2}	111
250	180	355	1.20×10^{-2}	108
500	355	710	0.90×10^{-2}	105
1 000	710	1 400	0.63×10^{-2}	102
2 000	1 400	2 800	0.45×10^{-2}	99

Note. The octave band with a geometric mean frequency of 8 Hz is used only for checking the oscillatory velocities of hand tools with speeds less than 11.2 rotations or cycles per second.

Table 13 enlists the maximum permissible limits of oscillatory velocities and their pressure levels in the octave bands of frequency.

Also, standard regulations for use of hand tools specify the force of the hand-pressure feed, mass of tools, and the values for the exter-

nal control force applied to pneumatic drives. The mass of hand-held tool or its parts taken on by the hands of the operator, pull of gravity or its component transferred to the hands of the operator during the work varies with the type of hand tool, but should not be more than 100 N.

Heat conduction coefficient of the machine, tool or tool part contact surfaces should not exceed 0.5 W/(m K). The standard also defined the general safety requirements for pneumatic hand tools and machines including the requirements for the safe construction, use, and the methods of checking the vibration parameters.

In addition, the design of a hand tool or machine must ensure protection of the operator's hands against vibration, guards for the working implement, and the diversion of the exhaust air from the operator by specially designed exhaust holes. Percussion (shock) tools should have protective devices to eliminate spontaneous sweep of the working tool during the idle run.

In the operation of the pneumatic drives and apparatuses, the value of the physical effort (control force) applied through the hands should not exceed 10 N; through hands to the elbow, 40 N, and one arm, 150 N, through two arms, 250 N.

The controls (handles, flywheel governors), except for remote control panels, should be mounted 1 000-1 600 mm and 600-1 200 mm above the floor or the control platform for the operation from standing and sitting positions, respectively.

The instrumentation should provide measurement and control of the vibration parameters (displacement, velocity, acceleration, frequency, phase and amplitude) of the workplaces (seats, operating decks and platforms) and the controls during the operation, also determination of the root-mean-square (rms) velocity in the absolute and relative values averaged over the time during which the measurements were taken. Determination of the rms acceleration can be made both in absolute and relative values, while that of displacement only in absolute values.

The instrumentation should ensure measurement of vibration in the octave and three-line octave bands of frequencies. The characte-

Table 14

Measurement limit, db	Root-mean-square velocity depending on mean rated frequency of octave filters, Hz												
	0.5	1	2	4	8	16	32	63	125	250	500	1000	2000
Lower	98	92	86	80	80	80	80	80	80	80	80	80	80
Upper	140												

Table 15

Measurement limit, db	Root-mean-square acceleration depending on the mean rated frequency of octave filters, Hz												
	0.5	1	2	4	8	16	32	63	125	250	500	1000	2000
Upper	80	88	88	92	98	104	110	110	110	110	110	110	110
Lower	50												

ristics of the octave and three-line octave filters are standardized, but the dynamic range of a filter should not be less than 40 db.

The instrumentation must provide for the determination in the octave bands of the rms velocity relative to 5×10^{-8} m/s in accordance with the data in Table 14, and that of acceleration relative to 3×10^{-4} m/s, in accordance with the data in Table 15.

Measuring devices are normally made in the form of portable instruments.

4.3. SOME PRACTICAL APPLICATIONS OF VIBRATION CONTROL PRINCIPLES

Measures to control, measure and monitor vibration and minimize or eliminate its harmful effect on people, instruments, machines and structures must be taken during the design, construction or manufacture and use of industrial equipment and structures. Finding the source and the cause of vibration should be followed by a proper study of the vibration spectra. The knowledge of the amplitude-frequency characteristics of vibration is the key to implementing the technical measures aimed at eliminating the causes of harmful vibrations. Of no less importance for the prevention of vibration is proper operation of the equipment, regular checking, maintenance and repair.

The objectives of harmful vibration control can be achieved by fulfilling the general safety recommendations which rely on the antivibration engineering, organizational and medico-preventive measures.

The *engineering measures* include antivibration engineering facilities, such as devices for the prevention, suppression, damping and insulation of harmful vibrations, use of automatic devices to avoid contact with the vibrating body, changes in the design parameters of machines, equipment and mechanized tools.

The *organizational measures* can be strict supervision of the operations during erection and installation of equipment at industrial sites, observance of the maintenance schedules, and instructions.

The *medico-preventive measures* are aimed at ensuring the necessary microclimate and a set of physico-therapeutic procedures (baths, massages, the UV-irradiation), introducing physiologically grounded periods for work and rest for persons subject to vibrations, and providing personal protective equipment to the workers.

One of the problems of vibration engineering is the protection of people, instrument, machine, and structures against the effect of harmful vibration. Measures taken in addition to the ordinary passive vibration isolation requiring no extra energy sources include automatic control systems, signalling and remote control devices. Among other measures are static and dynamic balancing, the selection of inertial and elastic parameters that avoid operation in regions of resonance, damping units (when it is impossible to operate far from a resonance region), dynamic vibration damping by the addition of specially tuned vibration units (a mass on a spring or a pendulum), or impact vibration units (small spheres striking a wall), and gyroscope installations to damp angular vibrations. Active vibration insulation (automatic suppression of vibrations) is also used. The objectives of dynamic vibration control can be damping, amplification or stabilization. Dynamic amplification is attained by turning the system to a resonant condition. With some adjustment in systems having two or more masses it is possible to achieve dynamic amplitude stabilization for induced vibrations that becomes almost independent of changes in the vibrating masses or the stiffness of certain elements.

Vibration isolation facilities are provided to minimize vibration effects transferred from the vibration source to the worker's body by introducing deformable elements between the vibration source and the object being protected. Passive vibration isolation is used; in this case the isolators are intermediate elements that are deformed by the action of the vibration source. In stationary equipment installations protection against vibration can be achieved by the appropriate construction of the basements (Fig. 42) or use of vibration isolation supports or pads.

The basement for machine-tools and equipment with unbalanced masses includes "acoustic gaps" or movement arrestors filled with a porous material and a functional joint at the base-line. The base-line should run deeper than the structural foundation to reduce the transfer of jolts to the walls and other structural elements of the building. When mounting machines and equipment that are likely to produce vibration during the operation their frames or beds must be underlain with the vibrated insulating materials.

In calculating a basement, attention is paid to the amplitude of its foot oscillation which should not exceed 0.1-0.2 mm, and for high-precision equipment, 0.005 mm. Vibration isolation supports are provided under the bed or frame of large-sized installations. To

ensure an effective vibration insulation, the mass of supports or pads should be large as far as practicable.

The efficiency of vibration isolation is determined by the coefficient of transfer (TC), equal to the ratio of the force F_{base} acting on the basement having an elastic element to the force F_{mach} acting with a rigid element:

$$TC = F_{base}/F_{mach}$$

The value of TC for an effective isolation varies from 1/8 to 1/15 if the ratio of the induced oscillation frequency to the natural frequency of the system equals 3-4.

The alternative solutions to the reduction of oscillation transfer from the vibration source to its basement can be the replacement of

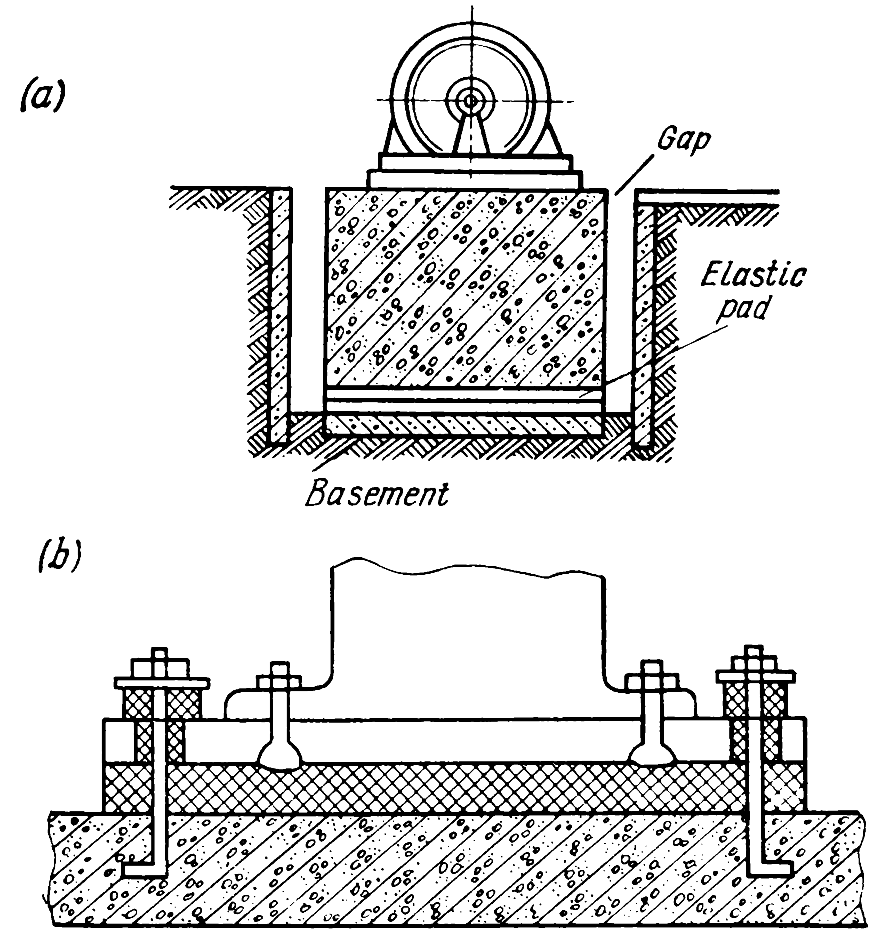

Fig. 42. Vibration isolation devices
(a) basement with an acoustic gap; (b) vibration isolation pads

stiff connection between them by elastic elements (Fig. 43). These elements can be steel springs or pads from rubber, cork, bitumen-impregnated felt, etc. Note that the use of spring-type vibration isolators and insulating pads from elastic materials is feasible only for damping high-frequency vibrations arising from the operation of machines running at speeds higher than 2 000 rpm. The elasticity of such pads and isolators may often be insufficient for damping low-frequency vibrations and may even increase the transfer of the

oscillation to the basement. The application of vibration isolation facilities should rely on the calculation of the elastic elements, i.e. area and thickness of pads and the elastic characteristics of springs. Floors can be made of slabs or include isolating cushions from vibrated insulating materials.

Among the materials used for vibration isolation purpose are (a) various sorts of soft, sponge and semi-rigid rubber; (b) natural cork, or boards of cork crumbs; (c) soft or rigid felt; (d) 3-5 cm thick sheets of mineral felt with a bitumen binder; (e) 3 cm thick boards of 50% asbestos and 50% cement; (f) 2.5 cm thick fibre-boards.

Elastic (deformable) elements (inserts) can also be effective to minimize or eliminate vibration of air ducts at points of connections to fans or at passages through structural elements of buildings (Fig. 44), or at points of ties of bearing structures with floors.

Vibration support or pads should be rigidly anchored to prevent horizontal displacement.

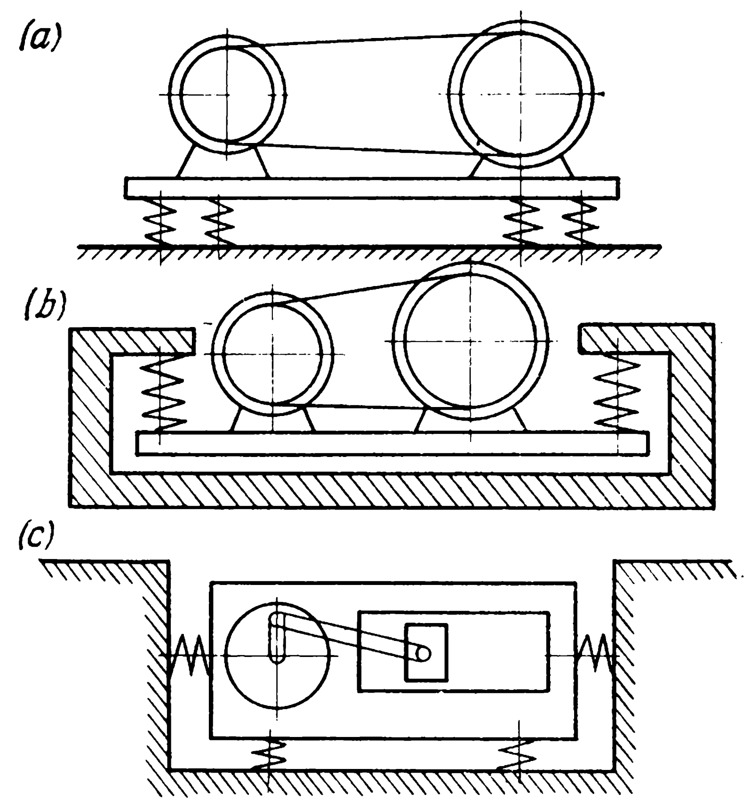

Fig. 43. Alternatives for isolating equipment capable of vibrating
(*a*) load-bearing; (*b*) suspension; (*c*) combination against vertical and horizontal vibrations

Vibration can be reduced by changing design features in machines and equipment. Thus, in mechanical diagrams dynamic processes from shock, or sharp acceleration can be avoided or reduced, for example, by replacing cam gears and crank shafts with uniform rotation gears or hydraulically-driven mechanisms.

Construction materials that fully meet the requirements of vibration damping are plastics (casings, handles), kapron (nylon), wood (inserts) fibre-laminate (gears), and rubber.

Automatic control and signaling. Vibration parameters vary durring the operation of one and the same machine or equipment. To determine changes in vibration by mere perception is difficult and therefore control and measurement of vibration parameters (displacement, velocity, acceleration, frequency, phase and amplitude) are essential. The instruments used include vibrometers, accelerometers, and vibrographs. There are two methods of determining displacement, velocity, and acceleration: by measuring the quantities relative to

a frame of reference independent of the vibration body and by measuring the deformation of an elastic member by means of an inertial element coupled to a vibration body.

Remote control, control of apparatus by means of one or more switches usually of the push-button type, situated at some distance from the apparatus has found wide application in the industry and promises to extend further. It excludes permanent or periodic presence of the operator in the zone of harmful vibrations which is dangerous to health and conducive to accidents.

Hand tools. A large number of injuries are caused by hand tools and machines. Generally speaking, the hazards inherent in hand machines and gears are many and vibration is one of them. There are

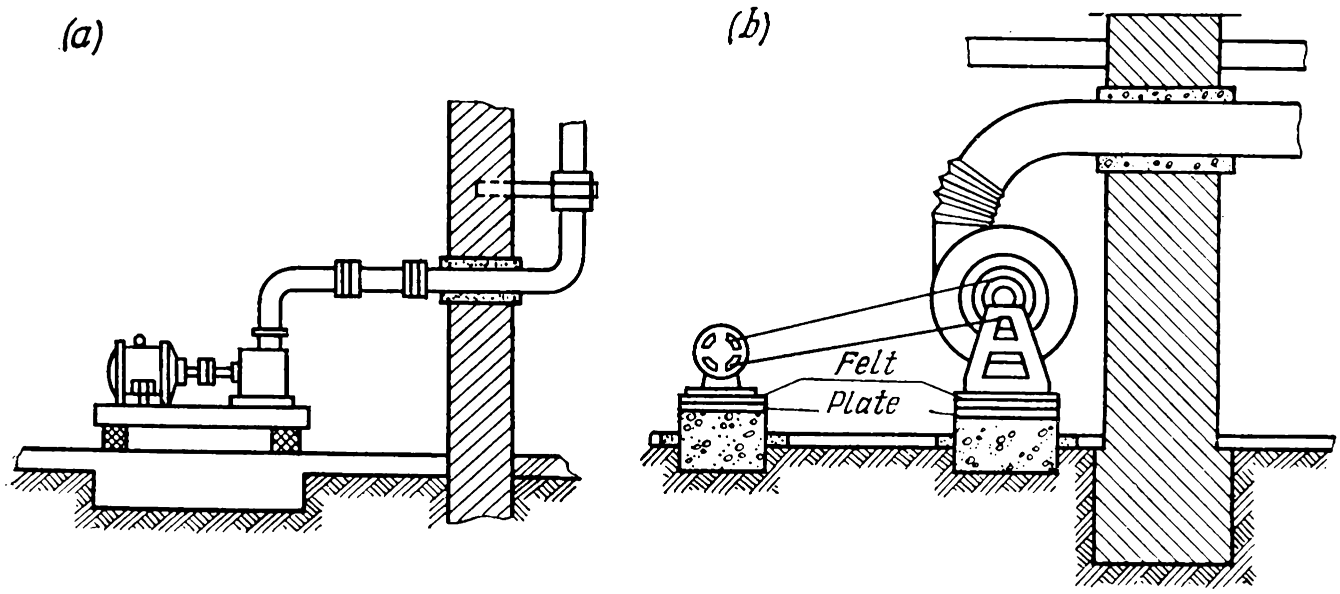

Fig. 44. Elastic inserts at points of support and passage through walls
(a) water pump; (b) fan

many antivibration devices that are used in hand tools to protect the hands against harmful vibration. For example, riveting and other type hammers include pneumatic shock-absorbers and elastic handles. Harmful amplitudes can be reduced two-fold by using lightweight strikers from polymeric materials and providing the hammer system with air cushions between the striker and the blockhead. Pneumatic hand drills and similar type machines use various vibration damping units that operate by compressed air. In rotary type machines, a 10 to 20 decibel reduction of harmful vibration can be attained by proper balancing of the rotating masses. Lowering of vibration levels in reduction gears and gear drives can also be achieved by using, instead of spur gears, other types of gear with a different kind of meshing (hearingbone, single-helical, etc.). To achieve the aim, it is feasible to substitute plastic and fabric-based laminate gears for metal gears. The precision of finishing and the accuracy of assembling of mechanisms is essential for minimizing vibration.

Static and dynamic balancing of rotating masses is also a measure to eliminate vibration of unbalanced parts. In grinding machines improved quality of grinding wheels with a minimum of disbalance, mass, and specialized appliances for dynamic balancing permit application of wheels at speeds up to 80 m/s with a minimum of vibration. Mounting on the spindle of tools and mandrels not specified for the machine is prohibited.

Vibration damping. Avoidance of operation in resonance regions as well as damping of vibration is very important for the safety of

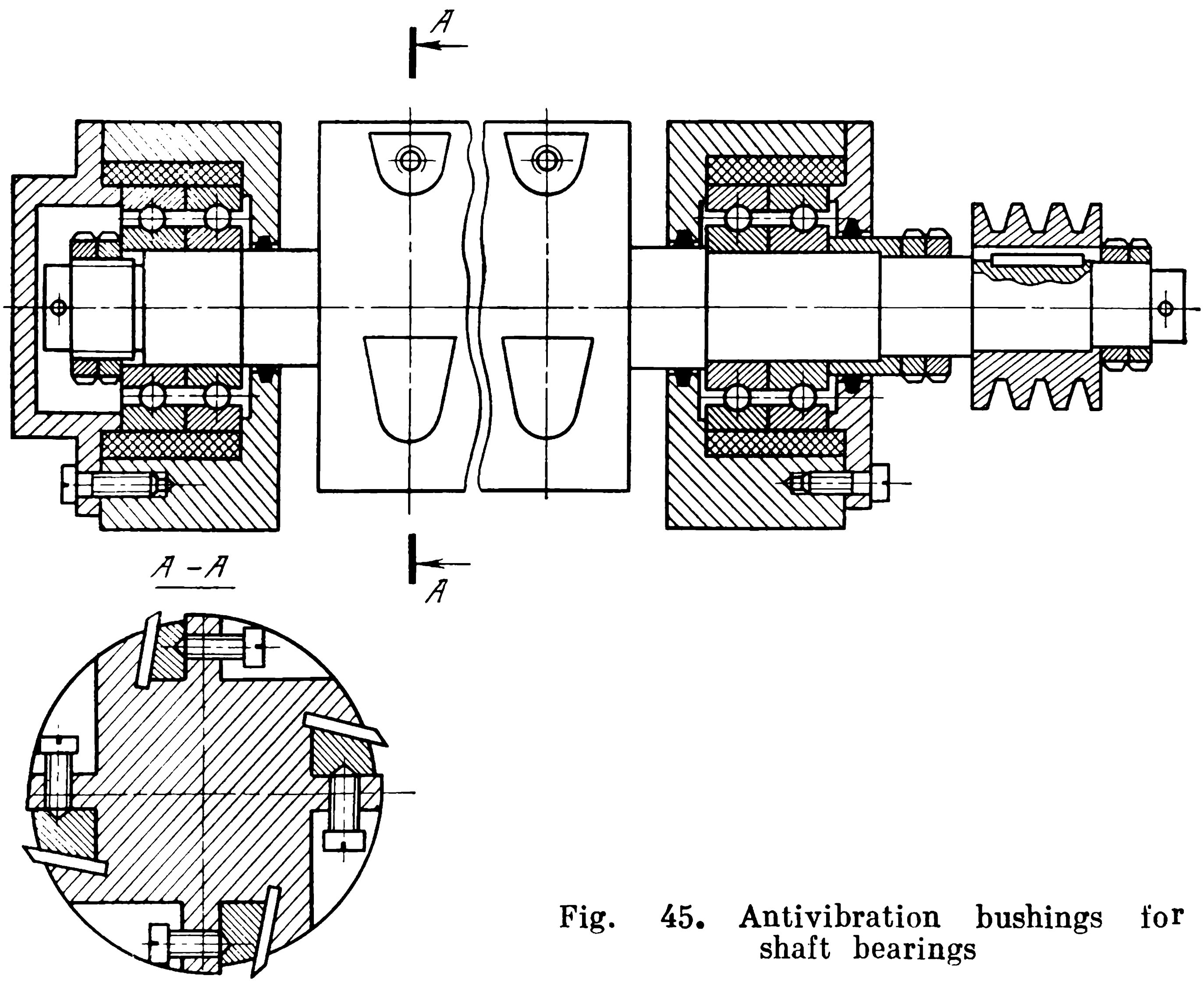

Fig. 45. Antivibration bushings for shaft bearings

industrial equipment and machines. To achieve both ends, attempts should be made to convert the energy of mechanical oscillations occurring in the machine into other kinds of energy by (a) using materials with high internal friction (Fig. 45); (b) applying on surfaces viscoelastic materials with high internal friction; (c) utilizing surface friction by introducing into the design additional absorption elements or a coating to increase active losses in the system; (d) converting oscillatory motion energy into the energy of eddy (Foucault) currents, or electromagnetic field.

Sufficiently effective for these purposes are viscoelastic coatings in the form of mastics applied directly on the working parts of machines and machine units. For toothed engagements, baths of lubricant materials are also a useful means for minimizing vibrations.

4.4. PERSONAL PROTECTIVE DEVICES

Suitable footwear with shock-absorbing soles affords protection to the worker from general vibration. Manufacturing specifications for such shoewear are standardized. Safety boots made of leather,

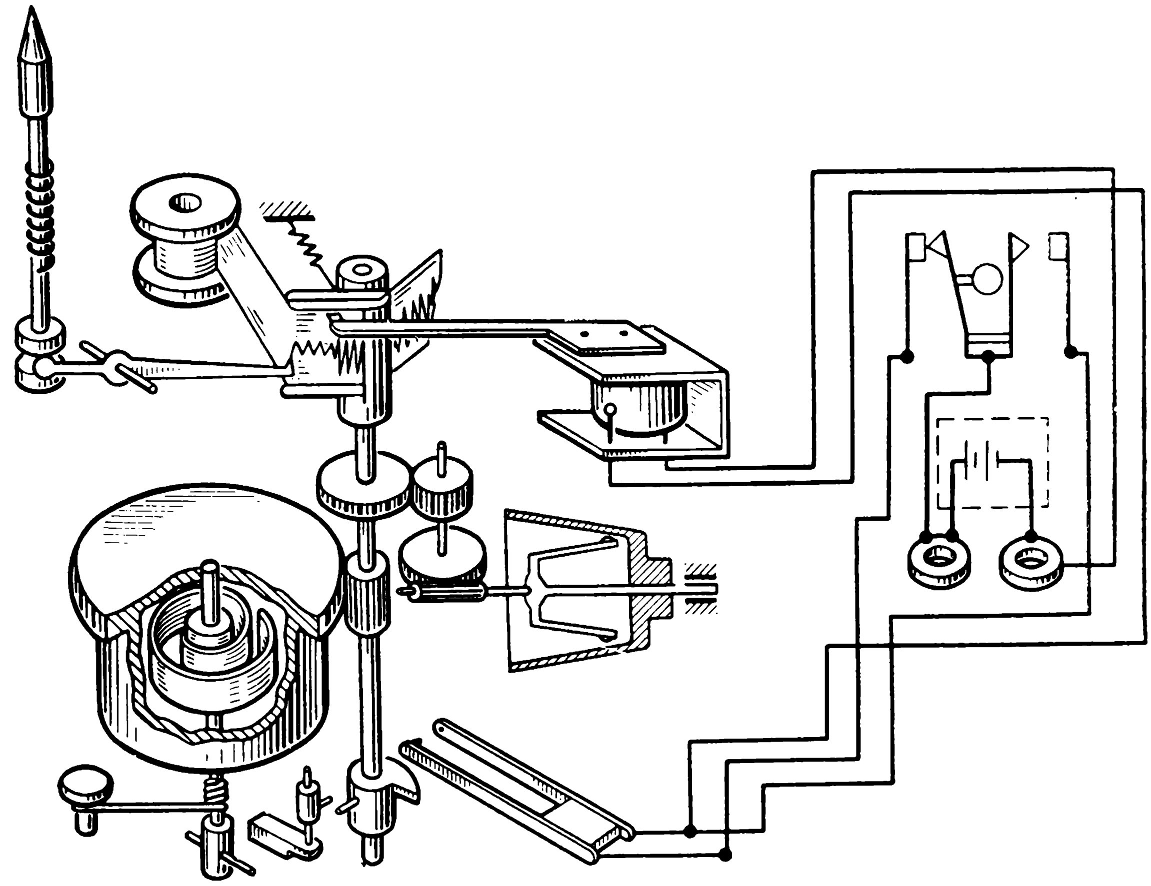

Fig. 46. A portable vibrograph

artificial or synthetic materials or combinations of these are meant for the protection of persons against general vertical vibration, inactive dust, and shock of 5 to 50 J. Special design of sole and elastic materials used for its fabrication make such shoewear effective against vibration. Safety standards include also requirements for the protection of hands from harmful vibration, which include use of gloves with elastic, shock-absorbing, inserts and special elastic devices to tack the vibrating handles, tools and workpieces. The effectiveness of such protective means is determined by the reduction in the level of vibration transferred to the hands and is equal to the difference in the oscillatory velocities (or the ratio of the absolute values) measured with and without the application of the protective devices.

4.5. INSTRUMENTATION

Vibration is measured by instruments based on the mechanical and electric methods of measurement (Fig. 46). Mechanical measuring devices, due to gaps and lag of the indicating and recording mechanism, give rather accurate readings only at relatively large amplitudes (more than 0.05 mm) and at low frequencies (up to 30 Hz).

Electrical instruments are superior to and more precise than the mechanical devices. They permit measurement over a wide range of frequencies for vibrations of a large and low intensity; vibrograms are obtainable at a considerable distance from the vibration body, which is both safe and convenient.

Home industry manufactures sets of noise analyzers and sound level (or noise) meters which permit measurement and recording of the vibration amplitudes from 0.005 to 1.5 mm in the frequency range from 15 to 200 Hz.

Sound level or noise meters can be used to measure the vibration of surfaces. They are connected through transition adapters to the vibration transducers with the output characteristics corresponding to those of the noise meter to indicate levels of the oscillatory velocity, instead of sound levels of pressure.

CHAPTER 5

Industrial Noise: Health Hazards and Their Prevention

Technical progress in all branches of industry and transport brings about the development and wide application of new equipment, machine-tools, and transport facilities. The growth of industrial capacities leads to the situation when man in everyday life and work

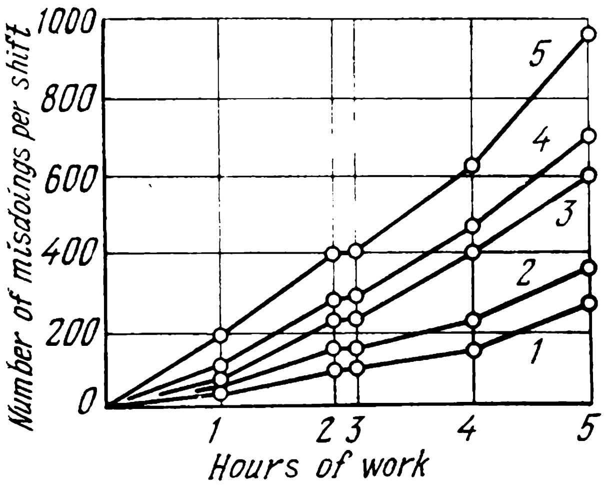

Fig. 47. Number of misdoings relative to the hour of work under exposure to general sound pressure of levels equaling to
1 — 76 db; 2 — 78-80 db; 3 — 85 db; 4 — 90 db; 5 — 95 db

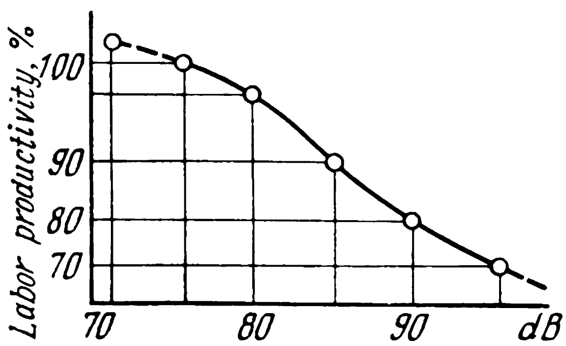

Fig. 48. Labor productivity *vs* noise level

is subject ever more to undesirable acoustic disturbances, i.e. noise of high intensity. The qualitative features of sensation during the perception of acoustic noise by the hearing organs and the body as a whole depend on the intensity (loudness) and spectral composition of the noise. The adverse effect of noise on the human organism is manifested in specific damage to the hearing apparatus of the body. Industrial noise reduces attentiveness (Fig. 47), increases energy losses by similar physical efforts, slowers the response of psychic reactions. The non-specific action of noise may be expressed as neurotic reactions, asthenia, and disruption of the functions of the autonomic nervous system. Coordination of movements is disrupted

and labor productivity is reduced (Fig. 48) under the influence of noise. Noise prevents quick response to sound signals from travelling cranes and loaders, etc., which may lead to injuries.

5.1. NOISE: PHYSICAL NATURE AND CHARACTERISTICS

Control of noise requires good knowledge of its physical nature, properties and basic laws of its propagation.

Noise is any undesirable sound which is objectionable to some persons, and which may or may not have significance. By extension, noise is any unwanted disturbance within an audio-frequency band. Technically, noise is defined as the class of sounds which do not exhibit defined frequency components, but comprise a frequency spectrum of energy. In everyday life "noise" implies various undesirable acoustic disturbances, as well as any sounds or combinations of these of various intensity (loudness) that interfere with rest or work.

Sound propagates in the transmission medium in the form of waves, sound waves. The region containing sound waves is called the *sound field*. The pressure and velocity of sound waves at each point of the sound field change with time. The oscillations generated by a sound source produce sound pressure which adds to the atmospheric pressure.

The dependence of sound pressure on time can be presented as the sum of finite and infinite number of simple sinusoidal fluctuations of this quantity. Each fluctuation is characterized by its physical root-mean-square value and a frequency. The frequency of a sound is the number of acoustic vibrations per unit time (second) measured in hertz (Hz). The acoustic vibrations are divided into three frequency regions, namely the infra (audible) sound vibrations with a frequency up to 20 Hz; sound (acoustic) vibrations in the frequency range from 20 to 20 000 Hz, and ultrasonic vibrations of a frequency higher than 20 000 Hz. Man percepts sound vibrations in the frequency range from 20 to 20 000 Hz. The audible range can be divided into a low-frequency band up to 400 Hz, medium-frequency band from 400 to 1 000 Hz; and high-frequency band above 1 000 Hz.

As a sound wave propagates, transfer of energy takes place. The magnitude of the sound wave measured by the transmitted energy, in ergs per second, through a square centimeter which is normal to the direction of propagation is known as the *intensity of sound*; *the symbol I*. The sound intensity can also be expressed in watts per square centimeter.

Sound pressure and intensity can vary within a wide range of values: up to 10^8 and 10^{16} times, respectively. It is important that perception of noise, which is often a mixture of random and periodic vibrations, by the ear is based not on the absolute but

relative changes in sound intensity because the intensity of sound (sensation caused by noise) is proportional to the logarithm of the sound source energy. In discussing sound measurements caution should be observed in using the term "intensity" and "intensity level". It is more desirable to use terms "sound pressure level" or "sound velocity level", since the relationship between the intensity and the pressure or velocity is generally unknown. Therefore, sound intensity level and sound pressure level are expressed as logarithmic quantities, in decibels (db).

The intensity level, in decibels, of a sound is 10 times the logarithm to the base 10 of the ratio of the intensity of this sound to reference intensity stated explicitly:

$$L_I = 10 \log I_I/I_0$$

where I_I is the intensity of sound at the given point, W/m^2; I_0 is the reference intensity of sound corresponding to the audibility threshold equal to 10^{-12} W/m^2, at 1 000 Hz.

The sound pressure level, in decibels, of a sound is 20 times the logarithm to the base 10 of the ration of the pressure of this sound to the reference pressure stated explicitly:

$$L_p = 20 \log p/p_0$$

where p is the sound pressure at the given point, Pa; and p_0 is the reference pressure equal to 2×10^{-5} Pa/m^2.

The relation between the levels of sound intensity and sound pressure can be written as

$$L_I = L_p + 10 \log \frac{\rho_0 c_0}{\rho c}$$

where ρ_0 and c_0 are the density and velocity of sound in the air at normal atmospheric conditions; ρ and c are the density and velocity of sound in the air at the time of measurement.

The term "sound pressure level" has been in general use for measurements of noise in the air and for the evaluation of its effect on man because in the apperception of noise the effective sound pressure, i.e. the root-mean-square value of the instantaneous sound pressures over the time interval at the point under consideration, is more important than sound intensity.

The scale of decibels[1] from 0 to 140 db is very convenient as it covers almost the entire range of audible sounds (Fig. 49). Table 16 gives an idea about the various sound pressure levels in decibels, from different noise sources.

---

[1] The decibel (db) or (dB) is one-tenth of a bel. The abbreviation "db" is commonly used for the term decibel. With P_1 and P_2 designating two amounts of power and n the number of decibels corresponding to their ratio: $n = 10 \log_{10} (P_1/P_2)$.—*Translator's note.*

Table 16

Noise source	Distance to noise source, m	Sound pressure level, db
Pocket watch	1	20
Whisper	0.3	40
Speech of average loudness	1	60
Metal-cutting machine-tools	Workplace	80-95
Pneumatic riveting, chopping	1	110-115
Prop engine	2-3	120-130
Jet engine	2-3 (from exhaust)	More than 140

Effective sound pressure of about 140 db is known as the threshold of feeling (pain) as it stimulates the ear to a point at which there is the sensation of pain, and any further increase of the sound pressure may cause rupture of the tympanic membrane, commonly known as the ear drum.

The logarithmic scale in decibels permits the determination of noise physical characteristics only because it is calibrated so that

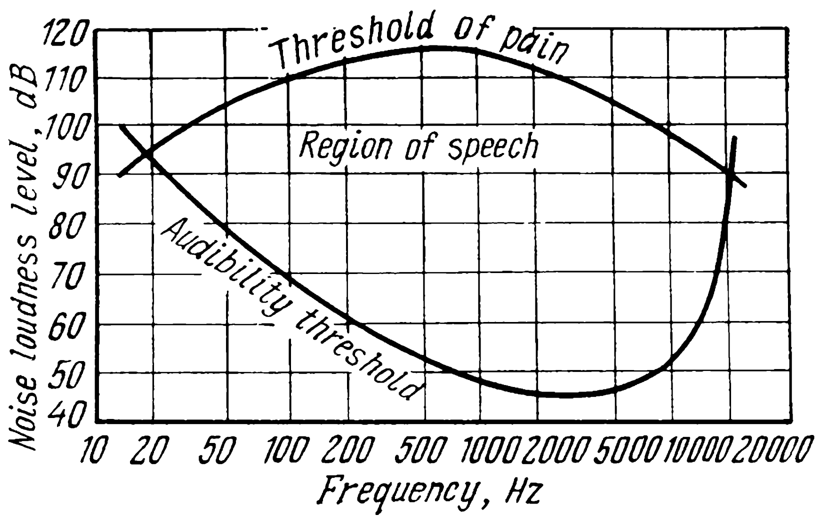

Fig. 49. Region of audible perception

the values of the reference sound pressure p_0 corresponds to the audibility threshold at 1 000 cycles per second (1 000 Hz). But the human ear is not equally sensitive to sounds of different frequencies. It is highly sensitive to sounds at 800 to 4 000 Hz, and less sensitive to sounds at 20 to 100 Hz. Therefore, to make physiological assessment of noise possible, equal loudness contours (Fig. 50) have been obtained from the studies on the subjective perception of loudness by ear of sounds at different frequencies. Loudness is thus a subjective measure of the intensity of a sound, or noise. Stated differently, loudness is the intensive attribute of an auditory

sensation in terms of which sounds may be ordered on a scale extending from soft to loud. Loudness depends primarily on the sound pressure of the stimulus but it also depends on the frequency and wave form of the stimulus. This subjective measure cannot be translated into objective measurement, but equalities of loudness can be adjusted subjectively. Now, loudness level of a specified sound is the intensity of the reference tone, 1 000 cycles per second, which is adjusted to equal, in apparent loudness, the specified sound. The adjustment of equality is made either subjectively or objectively, as in a noise meter. Loudness levels are measured on

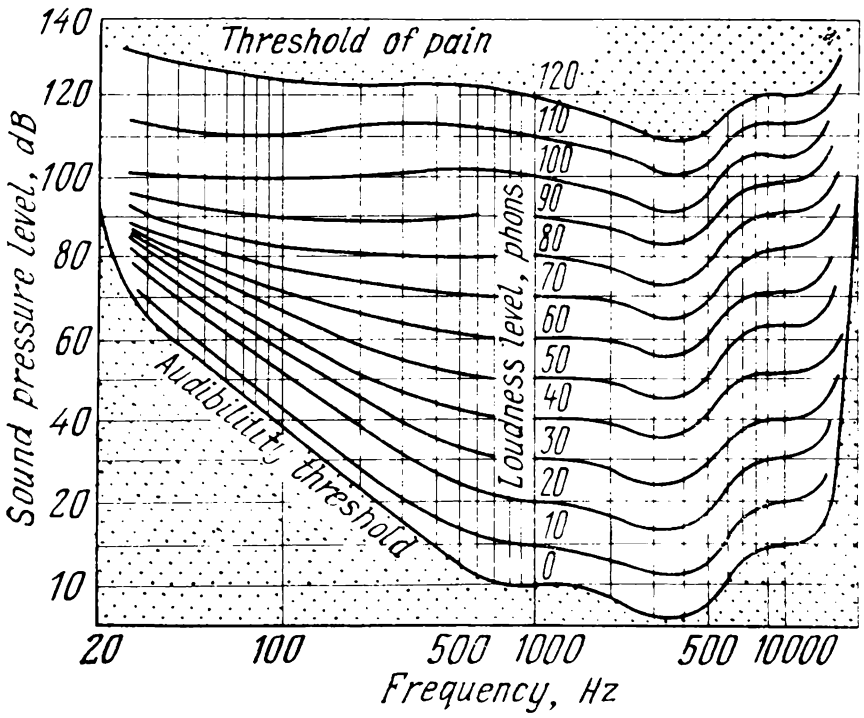

Fig. 50. Equal loudness contours

the phon scale[1]. The sound loudness level in phons is assumed to be numerically equal to the sound pressure level in decibels relative to 0.0002 microbar of a simple tone of the reference frequency 1 000 Hz which is judged subjectively to be equivalent in loudness.

The set of simple harmonic waves into which a sound wave can be resolved is known as the sound spectrum. The spectrum expresses the frequency composition of the sound and is obtained by analysing the sound. It shows a continuous range of frequencies, usually wide in extent, within which waves have some common characteristics and commonly called the audio-frequency spectrum or spectre. Audio-frequency is any frequency corresponding to a normally audible sound wave, and ranges roughly from 15 to 20 000 cycles per second. An audio-frequency spectrum is usually represented in

[1] The scale of intensity of 1 000 cycles per second reference tone, with decibels steps above the agreed threshold of the aural perception which is used as an objective loudness scale for noise and other sound measurements. Also called sound-level scale.—*Translator's note.*

a coordinate plane where the frequency is plotted along the axis of abscissae and the root-mean-square values of the sinusoidal noise components (or sound pressure levels, in decibels of these components) are plotted on the coordinate axis.

Sound spectra are determined with sound analyzers which are devices for measuring the band pressure level or pressure spectrum level of a sound as a function of frequency using a set of filters of a desired frequency band. The whole range of frequencies is divided into octave bands of which the commonest (see below) are those where the upper cut-off frequency is twice the lower cut-off frequency, the geometric mean of the upper and lower frequencies specifying the band as a whole.

Octave band geometric mean frequency, Hz . . .	63	125	250	500	1 000	2 000	4 000	8 000
Lower and upper cut-off frequencies of octave band, Hz	45-90	90-180	180-355	355-710	710-1 400	1 400-2 800	2 800-5 600	5 600-11 200

Noise spectra are measured to compare noise from different machines and to rate loudness in industry. Three-line octave (band) filters, octave analyzers[1] and sound-level meters (sometime called noise meters) are used for detailed studies of noise sources.

According to the character of the frequency spectrum, noise can be classified into *large bandwidth noise*, i.e. noise with a continuous spectrum wider than 1 octave, and *tonal noise* which spectrum has audible discrete tones.

When classified according to the time characteristic, noise can be stationary if the loudness level during the 8 h interval changes by not more than 5 db (A)[2], and nonstationary, if the loudness level changes with time by not less than 5 db (A). Nonstationary noise in its turn can be subdivided into the intermittent, time-varying and impulse noise.

Intermittent noise is characterized by a sharp fall of the sound level due to the background noise[3] level. The length of time during which the sound level remains constant and higher than the background noise is one second, and more.

Time-varying noise is noted for a sound level which continuously changes with time.

---

[1] It is a filter in which the upper cut-off frequency is twice the lower cut-off frequency.—*Translator's note.*

[2] Scale A of the sound-level meter (for details, see Sect. 5.5).—*Translator's note.*

[3] Noise due to audible disturbances of periodic and/or random occurrence.—*Translator's note.*

Impulse noise is a noise signal 1 to 200 ms in length characterized by transient disturbances separated in time by intervals of more than 10 ms (butt less than one second) and perceived by the ear as successive acoustic shocks.

Sound power is the major characteristic of a source, determined as the total sound energy radiated by the source per unit time. The commonly used unit is the erg per second, but the power may also be expressed in watts.

Equipment pieces or machines as sound sources of the same sound power may produce different sound pressure depending on whether they are in the open grounds or in an enclosure. Sources may radiate sound energy in one direction more than in other directions (i.e. the spatial distribution of the sound energy is not uniform). The directivity factor F for sound emission is therefore used to account for this phenomenon.

Technical specifications of equipment or machines include noise characteristics such as sound octave-band power levels and sound directional characteristics. The level of sound power L_p in decibels is assumed to be numerically equal to the sound intensity level:

$$L_p = \log P/P_0$$

where P is the sound power, W; and P_0 is the reference sound power equal to 10^{-12} W.

In addition, specifications usually include sound octave-band pressure levels (band pressure levels) measured at a certain distance from the machine, and sound loudness levels, at 1 m from the machine.

In designing new industrial premises, it is obligatory that the acoustic analysis be made for specified points of industrial building and enclosures to ensure safe levels of sound pressure. The objectives of the acoustic analysis are:

(1) determine the sound pressure levels at specified points, given the source of noise and its noise characteristics;

(2) establish the extent to which loudness of noise should be reduced; and

(3) assign measures aimed at reducing excess noise to maximum permissible limits set by the standard.

It is customary to use the following formulas in acoustic analysis:

$$L_p = L + 10 \log [F/4\pi r^2 + 4/B], \text{ and}$$

$$L_p = L + 10 \log F - 10 \log S - \Delta L_P$$

in which L is the source sound power level, db; L_P is the sound pressure level, db; F is the directivity factor; r is the distance from the source geometric center to the specified point, m; B is the enclosure constant, m^2, $B = A/(1 - \alpha_m)$; A is the equivalent area of absorption, m^2, $A = \alpha_m S$; α_m is the mean coefficient of absorption

of interior surfaces; S is the area equal to the surface on which radiant energy is incident; ΔL_P is the reduction of the sound energy with distance (at a distance of 50 m $\Delta L_P = 0$).

The acoustic effects such as echo, resonance, interference and diffraction, associated with sound, i.e. sound wave propagation, should also be taken into account.

Echo is a sound wave which has been reflected at one or more points in the transmission medium, or otherwise returned with a sufficient magnitude and delay to be perceived in some manner as a wave distinct from that directly transmitted.

Resonance is the enhancement of response to an acoustic pressure for a band of frequencies, the response increasing to a maximum and then decreasing as the frequency is increased through the frequency of resonance.

Interference is the effect of superposing of two or more trains of waves of equal wavelength. As most commonly used, the term refers to the interference of waves of the same or nearly the same frequency. Wave interference is characterized by the phenomenon of the occurrence of local maxima and minima of wave amplitude. There is destructive interference if the phases and amplitudes are such as to reduce the square of the resultant amplitude. Sound interference results when the waves concerned are sound waves.

Diffraction is the alteration in the direction of the propagation of a sound wave due to change in velocity over its wave-front, either owing to stratification of density or to varying velocity of wind with height. The term also refers to the property, exhibited by all electromagnetic waves, of curvature around the edges of an obstacle in their path. It is one of the factors which account for the propagation of radio waves around the curved surface of the earth.

Short waves are reflected from obstacles leaving behind a shadow zone which is a region, usually in the atmosphere (or under water) in which ray acoustics[1] predicts zero penetration of sound rays. The principle is used in acoustic construction and sound-proofing by providing soundproof surfaces (walls, structures) whose geometric dimensions are determined by the sound frequency and the distance to the source.

The operation of fans, pneumatic tools, washing machines, sand-blasting and hydraulic devices give rise to aerodynamic noise due to strong swirling or sudden expansion of flows of air, gas or fluid in the conduits.

---

[1] Ray acoustics, the analysis of acoustical problems under the assumption that sound travels along straight lines or rays in passing through homogeneous material. Diffraction effects are neglected. The methods of ray acoustics are applicable only if the state of the medium and the boundaries of the medium change only slightly over a distance equal to the sound wavelength.—*Translator's note.*

In some production areas where the equipment and machinery are crowded, the noise they produce may result in an effect called audio-masking which can be defined as the loss of sensitivity of the ear (hearing loss) for specific sounds.

Audio-masking may sometime reach a value[1] at which speech becomes illegible, i.e. unintelligible. This hinders or prevents normal communication between the workers controlling or operating the same process at different sites, and may lead to situations dangerous to both the machines and the people operating them. If the masking effect accounts for 20 db, normal speech is still legible, becoming absolutely unintelligible as it reaches 70 db, and more.

5.2. STANDARD REQUIREMENTS FOR INDUSTRIAL NOISE LEVELS

The standardized parameters for noise are the level of sound pressure, the sound loudness level, the equivalent (effective) loudness level, and the frequency.

Table 17

Workplaces and work zones	Octave band geometric mean frequencies, Hz								Apparent and equivalent loudness level, db (A)
	63	125	250	500	1 000	2 000	4 000	8 000	
	Sound pressure level, db								
Design office, lab. facilities; first-aid and health centers, etc.	71	61	54	49	45	42	40	38	50
Managerial office	79	70	68	58	55	52	50	49	60
Observation and remote control cabins:									
without intercom	94	87	82	78	75	73	71	70	80
with intercom	83	74	68	63	60	57	55	54	65
Precision assembly room; typing office	83	74	68	63	60	57	55	54	65
Experimental laboratory; "noisy" computer rooms	94	87	82	78	75	73	71	70	80
Open ground	99	92	86	83	80	78	76	74	85

The standard parameters of noise must be observed and maintained at all workplaces in the manufacturing industries as maximum permissible limit values. For high audio frequencies, which are most harmful and unacceptable to the human ear, the standard sets lower

[1] The unit customarily used is the decibel.—*Translator's note.*

levels of sound pressure as against sounds of lower audio frequencies. The length of exposure and character of noise can be accounted for by using correction tables that supplement the basic rates under the standard.

An approximate estimation of noise levels can be done by measuring the general noise level with a sound-level meter switched on scale A. In this case, the rated parameter is the equivalent loudness of sound in decibels with a designation A [db (A)]. The maximum permissible levels of sound pressure (db) and loudness levels, in db (A), for permanent workplaces within industrial premises and in the open production grounds are listed in Table 17.

It should be noted that the maximum permissible limits of noise for various kinds of workplaces, as set by the standard, are based on the character of work not on the type of equipment.

Work zones in which the loudness level exceeds 85 db must be noted with danger signs, and the workers be provided with personal protective equipment. Presence (even short stay) of persons in the work zones where the levels of sound pressure measured in any active band exceed 135 db is prohibited.

Averaged frequency spectra for certain types of machines and industrial equipment used at manufacturing plants is given in Table 18.

Industrial equipment is regarded as "noisy" or noise-making if the loudness levels measured at workplaces exceed the established maximum permissible levels reduced by 10 db.

Simple arithmetic summation of sound pressure levels does not give the total sound pressure produced by several sources at a given point of the transmission medium. With two sources characterized by loudness levels L_1 and L_2 (db), the total loudness level L_t produced is

$$L_t = L_1 + \Delta L$$

where L_1 is the highest of the two levels, and ΔL is the correction factor that depends on the difference between the loudness levels:

Difference $L_1 - L_2$, db	0	1	2	3	4	5	6	7	8	9	10	15	20
Correction factor, ΔL, db	3.0	2.5	2.0	1.8	1.5	1.2	1	0.8	0.6	0.5	0.4	0.2	0

We shall illustrate this by way of example. Of the two apparatuses, each produces noise of 90 db measured at the control panel. The total noise from them is $90 + 3 = 93$ db.

If one source has $L_1 = 90$ db and the other $L_2 = 84$ db, the difference in noise levels is $L_1 - L_2 = 90-84 = 6$ db; the correction factor from the table $\Delta L = 1$ db. The total noise level from the two sources $L_t = 90 + 1 = 91$ db.

Where there are several sources of noise, such calculation proceeds successively from the sources of the intensier noise. Where the noise

Table 18

Machine-tools and equipment	63	125	250	500	1 000	2 000	4 000	8 000
	Octave band geometric frequency, Hz — Averaged sound pressure level, db							
Turning lathes	78±4	80±5	84±4	85±5	85±6	84±5	80±5	80±5
Full automatic lathes	82±3	88±3	85±3	87±3	87±3	86±3	86±4	84±4
Planing machines	74±3	80±3	82±3	80±3	79±3	82±3	78±3	73±3
Slotting machines	75±3	78±2	79±2	80±2	79±2	77±2	72±3	63±3
Grinding machines	84±4	85±4	87±5	94±1	97±0	94±1	88±4	86±4
Tool-grinding machines	78±4	85±2	85±2	84±3	85±3	81±1	81±3	80±3
Profile-boring machines	66±1	66±2	71±2	75±2	74±3	71±2	64±2	57±2
Turning and boring machines	87±3	90±3	93±3	93±3	89±3	90±3	87±3	80±3
Drilling machines	81±3	82±3	83±7	86±3	85±4	84±3	90±3	84±4
Full automatic bulging machines	87±3	88±3	89±3	97±0	89±0	86±3	89±0	76±4
Plate (sheet) shears	92±3	95±3	94±3	95±3	95±2	90±3	93±2	92±2
Welding transformers	85±3	90±3	92±3	92±3	89±1	86±2	84±3	87±3
Pneumatic riveting presses	83±2	83±2	89±2	89±2	90±2	91±3	90±2	89±3
Pneumatic riveting hand hammers	99±3	106±4	110±3	111±3	113±3	113±3	112±3	114±3
Knock-out grids	96±4	104±2	104±2	105±7	104±4	102±3	99±3	95±3
Die casting machines (metal)	81±3	86±2	84±3	86±2	85±3	81±3	80±3	75±3
Moulding machines	97±3	99±3	100±3	99±3	98±3	97±3	96±2	96±4
Surfacing machines	90±3	94±2	100±3	101±3	98±2	94±3	95±3	90±3
Jointing machines	89±3	95±3	97±3	98±3	97±3	94±2	96±2	96±3
Milling machines (woodwork)	85±3	91±3	90±3	97±1	96±2	96±3	96±3	93±3

Note. The sign "±" indicates departures from the mean value.

level difference between two sources is more than 8 db, the noise from the weakest source can be ignored, since its contribution to the total noise is negligible.

From that, there are two postulates in noise suppression:

(1) for a sufficient reduction of noise from an apparatus, the noise from the strongest source in it should be suppressed;

(2) where similar sources of noise are many, suppression of noise from one or two of them does not practically reduce the total noise.

Measurement of noise characteristics should be performed in accordance with the established methods. Measurements are used in noise control to compare the actual (apparent) noise levels at work-

places in industrial premises to those established by the standard. Usually measured and calculated are the following quantities: the mean octave (band) sound pressure level L_P, in decibels, and mean loudness level, in db (A), the equivalent (in energy) sound loudness $L_{A\,equiv}$, in db (A), and the mean equivalent loudness level L_mA_{equiv}, in db (A) for nonstationary noises. Noise levels are measured at permanent workplaces. If the workplace is the work zone, measurements are made in at least three points of the work zone.

5.3. SOME PRACTICAL APPLICATIONS OF NOISE CONTROL PRINCIPLES

Noise control and the assessment of its effectiveness should be started at the stage of design or re-shaping of plants. When planning an area for an industrial development special attention should be paid to a rational physical positioning of separate buildings and design of workrooms within the buildings. Manufacturing processes that are likely to produce much noise, more than 90 db, must be located at separate buildings or otherwise isolated from the rest of industrial areas. One of the resources to achieve this end is the provision of acoustic gaps or movement arrestors along the perimeter of the foundation, filled with an insulating material. The other one may include free zones established between the "noise-making" departments or workshops. These free zones can be afforestated to increase the effect of isolation and complement the environment. A "green belt" about 50 m wide can considerably reduce the noise level as folliage is a good sound absorber.

When planning for production areas and departments inside buildings it is desirable to group the machine-tools and equipment by their noiseness and assign to them separate premises or area sections protected with a specialized sound-proof enclosure. Industrial premises with "noisy" processes should preferably be located on the windward side of the area.

The production areas with relatively calm processes or noiseless operations can be effectively protected from the external noise (from noisy work areas) through adequate sound-proofing of the walls and floors and other structural elements. In planning the sound proofing measures one should take into account the character of the dissipation of an emission (sound, in our case), some part of which, or of the energy associated with it, on striking a surface (wall, ceiling, etc.) is reflected, some absorbed, and only small part of it is able to penetrate through it (Fig. 51).

Manufacturing undertakings employ all sorts of pumping and ventilation units (fans) which are interconnected by complicated systems of pipelines or air ducts that usually pass through workrooms and production grounds. When in action, such installations

produce a lot of noise. To reduce noise from electric motors, pumps and fans, these last are installed on separate basements with sound (vibration) insulating pads or supports between them and their basements. Elastic inserts are used to couple pipes to pumps and air ducts to fans to reduce both vibration and noise resulting from it. Elastic pads, inserts or isolators are also used for noise reduction at points where pipelines and air ducts pass through the walls of the structures.

Of all the measures of noise control the elimination of noise at the source, i.e. directly in the apparatus, machine or mechanism, is most effective. The suppresion of noise at the source can be achieved through:

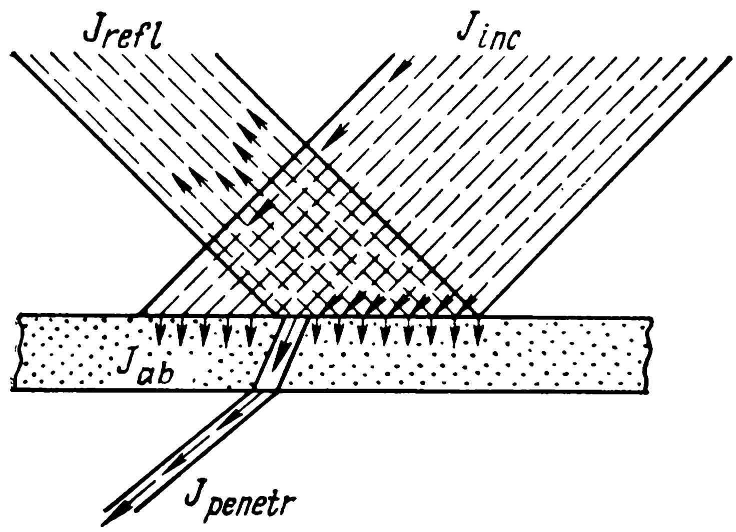

Fig. 51. Interaction between a surface and sound energy incident on it

J_{inc} — incident energy; J_{refl} — reflected energy; J_{ab} — absorbed energy; J_{penetr} — penetrated energy

— substitution of non-percussion processes and tools for percussive ones, e.g., use of hydraulic drives instead of cam or eccentric mechanisms, welding instead of impact riveting and straightening instead of forge-rolling, etc.;

— use of rotational, preferably uniform, motion instead of reciprocating motion;

— replacement of spur and chain gearing with V-belt and simple gear-belt transmissions;

— replacement of spur and chain pinions with helical and shevron (hearingbone) gears;

— substitution of plastic and other "mute" materials for metal. The combination of metal parts with those of plastic, e.g., steel gears with kapron of fibre-base laminate pinions, etc.

— use of lubricant baths for meshed gears, and forced-feed lubrication for articulated joints to minimize wear and noise caused by friction;

— use of lining, and elastic inserts in the joints to minimize or avoid transfer of vibration from one part of apparatus to another;

— reduction of the intensity of noise-making vibration of surfaces (jackets, casings, lid-covers, etc.) through stiff fastening or coating with sound-absorbing materials;

— use of rubber lining for inserts of metal containers and crates intended for the collection, handling or storage of workpieces.

Timely inspections and preventive servicing of equipment and machine-tools are exclusively important to avoid loose fastening and mismatch, and ensure accurate adjustment of the adjacing parts of equipment.

Sound-absorbing and soundproof finishing of room surfaces should be provided to place impermeable obstacles in the way of the propagation of sound waves. Noise silencers and sound absorbers must be installed as specified by the standard to suppress aerodynamic noises.

Sound-proofing includes construction of barrier structures, such as walls or partitions, to safeguard the workers from external noise. Sound-proofing utilizes the principle of reflection of sound, i.e. the greater part of sound energy incident on a surface is reflected and only its smallest part (1/1 000, and less) penetrates through it. Ideally, a sound proof structure should not let noise into an enclosure it safeguards. Sound energy penetrates through obstacles using their own vibrations. In other words, the obstacle itself becomes the source of noise and radiates sound energy into the room it is supposed to protect. Therefore, the more heavy (massive) the barrier-structure, the more sound-proof it is. As the acoustic resistance of the surface (its sound-proofness) is determined by its acoustic inertance it is more sound-proof to high-frequency sounds than to sound waves of low-frequency. Therefore, knowledge of the character of noise of the source is very important in sound-proofing. When constructing sound-proof structures it is essential not to forget that the external noise readily enters through any available opening or slot in the construction structure. This significantly reduces the sound-proofing effect of the structure. For example, external noise is easily heard through an open window or door. Naturally, making the wall thicker in this case would not be effective as the greater part of the external sound energy would penetrate through the window and only its minor part, through the wall. Consequently, airtightness of the construction is an essential condition for adequate sound-proofing. All the openings, untight closures in the walls should be properly sealed over the entire area and depth; doors and windows should be properly fit to match the perimeter, and the window frame grooves receiving glass, adequately putted. All these measures are essential for the isolation of rooms with noise-making processes or operations, and for the provision of sound-proof observation and operation cabins for the personnel operating such equipment.

Sound absorption is the process by which sound energy is diminished in passing through a medium or striking a surface. It utilizes the principle of absorption of sound energy incident on an obstacle in the way of its propagation. The more sounds (emissions) are absorbed, the less are reflected and this leads to the reduction of the total noise level within an enclosure.

Most of the construction materials (concrete, brick, glass blocks, etc.) absorb less than 2% of sound energy incident on their surfaces reflecting the rest 98% back to the room. Note that the level of noise

produced by a source located in the room is by 5 to 15 db higher in loudness than that produced by the same source in the open.

The application of the sound-absorbing materials with high coefficient of sound absorption for walls and ceilings permits the reflected noise to be diminished thereby reducing the total noise level in the workroom. Another benefit from sound absorption is the

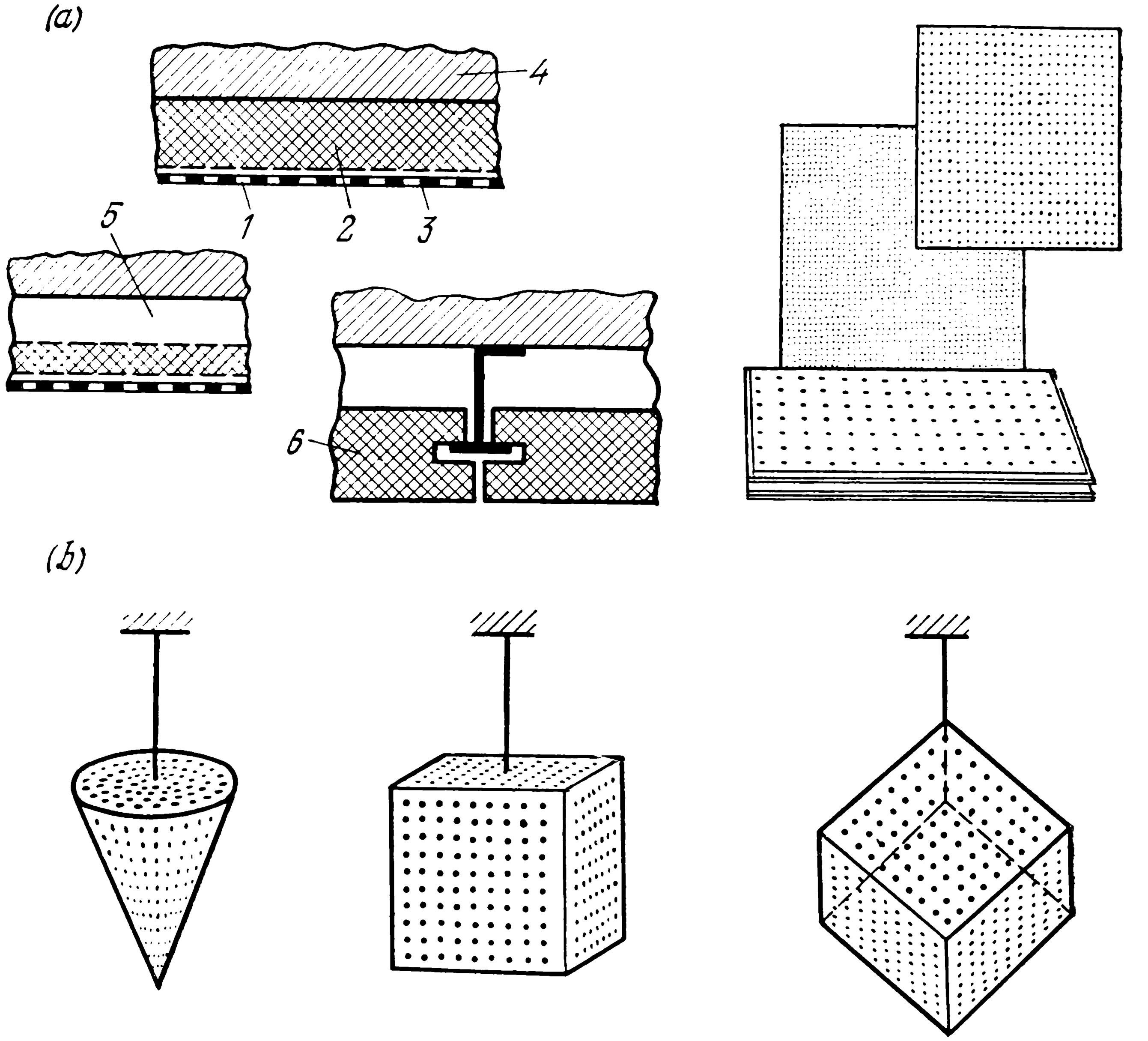

Fig. 52. Acoustic finishing of rooms

(a) sound-absorbing lagging; (b) functional sound absorber; 1 — protective perforated layer; 2 — protective glass cloth; 3 — sound-absorbing material; 4 — wall and ceiling surface; 5 — air gap; 6 — board from sound-absorbing material

possibility of easy aural checking on the operation of the machinery because where a direct sound prevails noise from every apparatus or lathe installed in the enclosure can be easily detected by the ear.

Ceilings and the upper portions of the walls 1.5-2.0 m above the floor level should be lagged with sound-absorbing material. The best effect from this measure is achieved when not less than 60% of the total area of the walls and ceiling in the room are lagged. Sound absorbing lagging may also help to reduce noise level by 6-8 db

which corresponds to 1.5-1.8 times reduction of noise loudness.

Where sound absorbing lagging of the interior surfaces is impossible or impracticable for technical reasons (equipment installations or piping), functional sound absorbers can suitably be used. They are usually made in the form of thin shells of acoustically absorbing

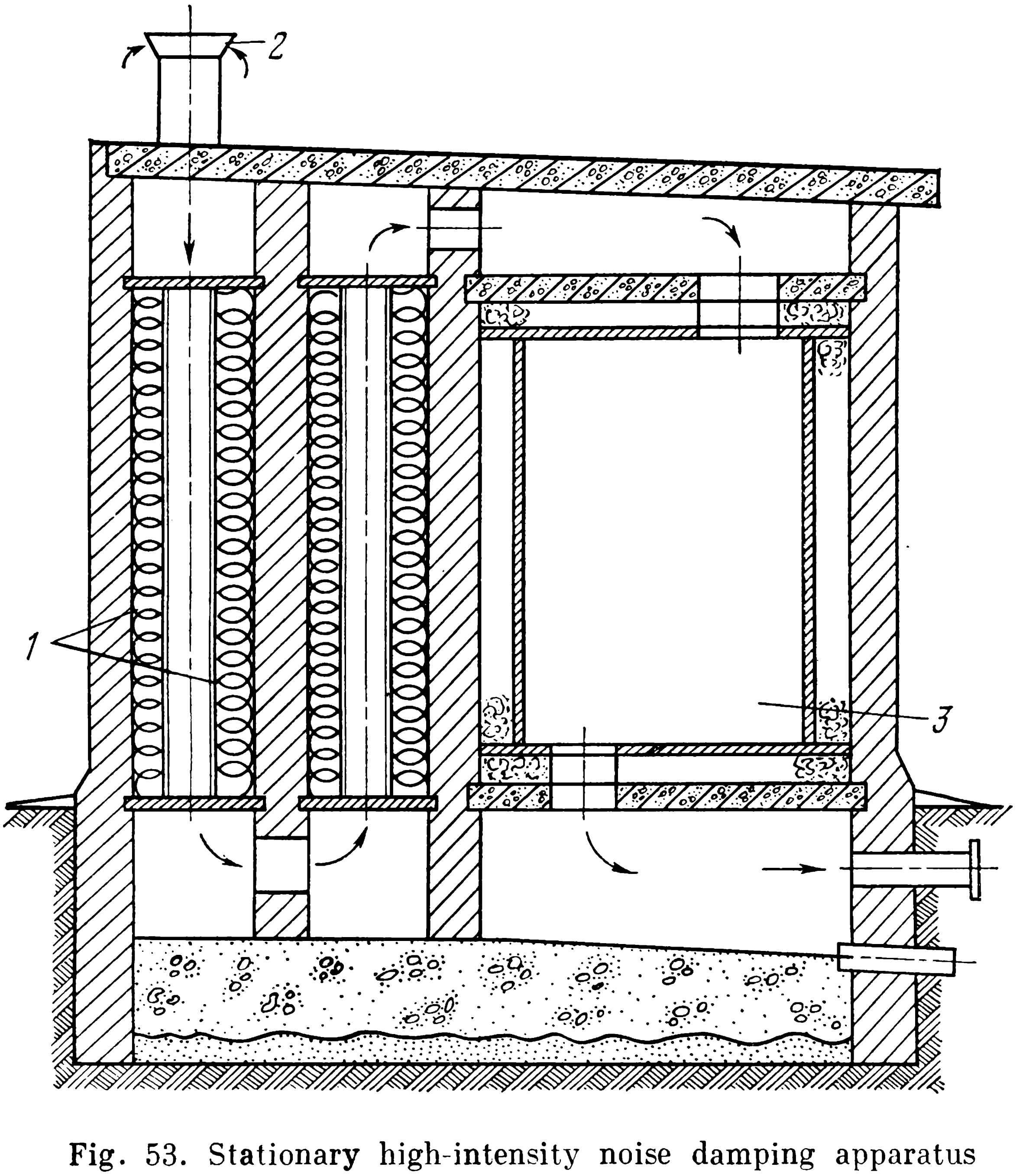

Fig. 53. Stationary high-intensity noise damping apparatus
1— active dampers; 2— air inlet; 3— expansion chamber with low-frequency noise damper

materials and suspended on wires. They are high efficiency absorbers and are often used in locations and premises where appearance is not a factor (Fig. 52).

Suppression of aerodynamic noise. Aerodynamic noises are sharp pulses[1] of velocity and pressure of air or gas flowing in conduits,

[1] A variation of a quantity whose value is normally constant. This variation is characterized by a rise and decay, and has a finite duration. This definition is broad so that it covers almost any transient phenomenon.— *Translator's note.*

occurring during the operation of pneumatic machines, engines, compressors, turbo-blowers, fans, ejectors, etc. To abate such noises at the source is practically impossible so they have to be suppressed or silenced. The aim is achieved by using various types of silencers and exhaust mufflers which deaden the noise by weakening the pulsations of pressure in a flow of air without causing resistance to the flow at the outlet.

There exist various types of silencers to suppress aerodynamic noise and reduce its effect on people. The so called "active silencers" have found wide application. They utilize the principle of absorption during which sound energy dissipates into heat energy. The simplest silencer of the type is the exhaust apparatus consisting of a casing having air channels, the inside surface of which is faced with a sound-absorbing material, and an expansion chamber. Passing through the channels, the air flow loses part of its sound energy; thus the output noise level is reduced (Fig. 53). The effectiveness of such exhaust silencer depends on the length of the lagged section of the channel and absorption characteristics of the lagging. The silencing effect can be improved by fitting in the channels lagged inserts of a smaller section. The sound-absorbing lagging is fine-fibre glass cloth and metallic or rigid PVC mesh cloth. To avoid vortex formation which reduces the efficiency of the silencer, the velocity of air flow is controlled within 12-15 m/s. The best effect in noise control can be achieved by applying various means of noise suppression in combinations.

5.4. PERSONAL PROTECTIVE EQUIPMENT

If properly selected and used, personal protective equipment and devices, such as sound-proof head-sets (helmets), earmuffs, earplugs and noise stoppers (Fig. 54) can afford effective protection against

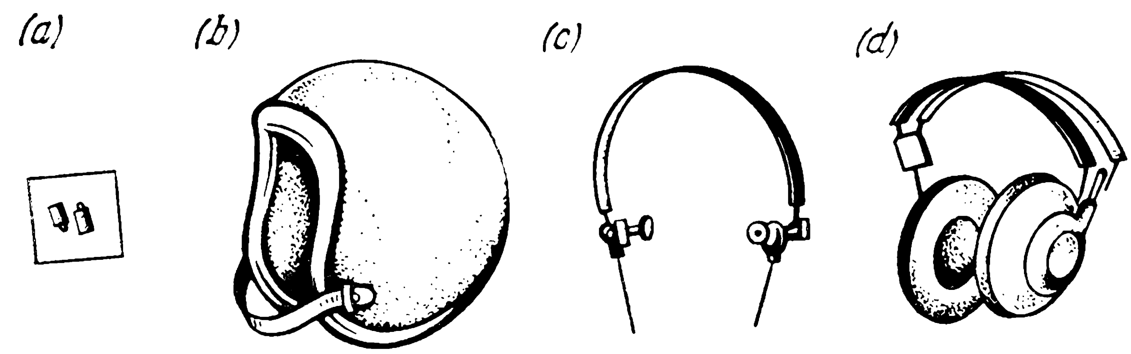

Fig. 54. Personal protection devices
(*a*) ear plugs; (*b*) helmet; (*c*) noise stoppers; (*d*) earmuffs

noise disturbances and prevent various functional disorders. To the extent that accidents and occupational loss of hearing may result from exposure to excessive noise, these devices are a preventive

measure, and can be used in addition to the principal noise control measures when the last for some reason or other prove ineffective.

Ear defenders are the simplest, cheap and convenient devices used to reduce the harmful effect of noise. They are conically shaped plugs of various materials for insertion into the ear to reduce perception of noise, particularly impulse noise. They can be soft or rigid. Rigid plugs are made of rubber or plastic materials while soft plugs are of cotton cloth or of very fine glass cloth impregnated with oil or a waxy mastic. Plugs do not prevent the wearer from wearing headpieces or goggles. However, during long use, ear defenders may cause discomfort and irritation in the ear, particularly at elevated temperatures. Application of multi-use ear defenders requires special medical supervision.

Earmuffs are large pads of rubber or similar material attached to a band or strap and worn about the head for reducing the effect of noise on factory workers (during impact riveting, straightening, chopping and the like operations). The device is light, convenient to wear and effective against noise of high frequency which is exclusively harmful to the human ear and the body as a whole.

Head-piece or helmet is an effective device against the effect of noise levels exceeding 120 db where the above protective devices are ineffective. High level of noise affects the skull causing the bones to vibrate. Such vibration adversely affects the auricular nerves and the brain function. Helmets provide adequate protection of the skull, particularly its paratideic region.

5.5. INSTRUMENTATION

Various instruments (sound-level meters, sound analyzers and vibrometers) are used to measure noise levels among which the sound-level meter, known as the noise-meter, is the commonest. This can be any form of meter which allows the operator to measure either objectively or subjectively, the loudness of a specified sound on the phon or decibel scale. One such device is the sound-level meter intended for measuring loudness (of noise) objectively. It uses the principle of conversion of sound energy into electric energy and consists of a non-directional piezo-electric microphone, an amplifier, corrective filters, a detector, and an indicator. The overall circuit design is such that the meter's characteristics approximate the property of the human ear. The sensitivity of the ear is a function of sound frequency, and this function varies with the intensity of the noise (or sound) being measured. Therefore, there are three sets of filters in a sound-level meter that provide the necessary contour of the frequency response at three loudness levels. Scale A conforms to the response for a low loudness level of $\sim$40 phons (it is used in the range of 20 to 55 phons); scale B, for a medium loudness level of

~70 phons (55 to 85 phons); scale C, for a high loudness level, ~85 phons (140 phons). The response at the high loudness level is uniform over a frequency band of 30 to 8 000 Hz.

Scale A is also used to measure the loudness level in decibels with the notation A, that is db(A), at any loudness level from 30 to 130 db at 50 to 8 000 Hz. The level of a sound level in db(A) is used when rating loudness in industry, dwelling, and transportation facilities. The filters are switched manually according to the loudness level of the sound (or noise) being measured. The rectified signal from the square-law detector is arranged over a time interval corresponding to the time constant of the ear — approximately 50 to 60 milliseconds (the time interval in which two separate acoustical signals are perceived as a unified signal by the ear because of its time lag). The scale on the output meter is calibrated in decibels relative to a root-mean-square sound-pressure level of 2×10^{-5} Pa on one of the three aforementioned scales A, B, or C.

Sound analyzer is a device for measuring the band pressure level in the loudness range of 25-180 db, and/or pressure spectrum level of a sound as a function of frequency, ranging from 50 to 10 000 Hz.

Vibration-noise meter (vibrometer) is an apparatus for the measurement, in the octave band frequency or generally, of the root-mean-square pressure levels of sounds of loudness between 30 and 130 db at 20-11 200 Hz; vibration velocity at loudness levels from 70 to 160 db at 10-2 800 Hz; and acceleration at loudness levels ranging from 20 to 130 db at 10-11 200 Hz.

Measurements are taken with a microphone at 1.5 m above the floor or operating platform (if work is performed in a standing position) or at head level (if the work is performed in a sitting position), directed toward the source of sound at a distance of not less than 0.5 m to the operator taking the measurement.

To check on the conformity of the actual noise levels in a production area with the standardized limits, the levels of sound pressure should be measured when not less than two-thirds of all the production capacities installed in it (industrial equipment units, machine-tools etc.) are operating in their standard (most often realizable) mode, with all ventilation and other noise-making units also in operation. The general rule is to measure noise levels not less than once in six months, with the results registered in a specified form.

5.6. ULTRASONIC RADIATION

Ultrasonic oscillations, i.e. ultrasonic waves, are mechanical vibrations and radiations propagating in solids and fluids which have frequencies in excess of those which, in a sound wave, are normally perceivable by the ear, i.e. above the audio frequency range (15 kilocycles). The general subject of acoustic phenomena in this

frequency range is known as ultrasonics. At one time, this subject was known as supersonics, but such usage is now deprecated. Although it is customary to refer to ultrasonic waves the elastic waves above 16-20 kilocycles, the standard adopts a considerably lower frequency (11.2 kilocycles) to ensure a gradual change from audible to ultrasonic oscillations.

Ultrasonic radiation has found wide application in various spheres of industry. Manufacturing industries, for example, use it for intensifying processes, such as cleaning, welding, mechanical treatment of metals, and for other operations. Well known is the ultrasonic detergent action, i.e. cleaning effect exhibited by the subjection of various materials mixed with conventional soap and water solutions to high-intensity ultrasonic radiation. The application of ultrasonic waves enhances the productivity of labor and improves product quality to a premium price. The scope of application of ultrasonic waves promises to expand further to include ultrasonic materials dispersion for the production of suspensions or emulsions due to the action of high-intensity ultrasonic waves, use of ultrasonic echo or transmission devices for the detection of flaws, such as hollows or cracks in optically opaque media, ultrasonic thermal action, and many other useful applications.

Sources of ultrasonic radiation in industry can be the industrial type devices for the production of sound waves of ultrasonic frequencies, called ultrasonic generators, and various other equipment in which ultrasonic radiation may occur as a concomittant effect during their operation.

Maximum permissible limits of ultrasonic radiation. The standardized limits of sound pressure apply also to the levels of pressure of sound waves in the range of frequencies above 11.2 kilocycles. The standard lays down the permissible limit values of sound pressure levels, specifies methods for the measurement, monitoring and control or reduction of harmful effects from ultrasonic radiation on the workers. The standard regulations do not apply to the cases of direct contact with the source transferring ultrasonic vibrations to the hands of the operator (solid or fluid media).

The permissible limits of ultrasonic pressure at workplaces are rated in the three-line octave bands of frequencies, and have the following values:

Geometric mean frequency of three-line band, Hz	12 500	16 000	20 000 and higher
Sound pressure level, db	75	85	110

The above levels of sound pressure levels are established for an 8 h exposure (length of the working day). These limits can be incre-

ased if the exposure time is less than 4 h (240 min) per working shift:

Total length of exposure per shift, min	60-240	20-60	5-15	1-5
Correction factor, db	+6	+12	+18	+24.

Sound pressure levels should be measured at workplaces at times when the "noisiest" process or operation takes place. Measurements are taken in the standard range of frequencies with the upper cut-off frequency being not less than the working frequency of the equipment of machine, and the operator in his normal working posture. Control measurements are taken at the starting of new equipment, after maintenance, and periodically during service life, not less than once a year.

Some practical applications of ultrasonic radiation control principles. Ultrasonic radiation should not be overlooked when dealing with safety. Safety precautions against high pressure levels of sounds of ultrasonic frequencies with the air being the medium of propagation, may take the form of:

— specially designed ultrasonic radiation sources (generators) operating at higher frequencies and emitting no parasitic ultrasound waves into the working environment;

— design measures to limit the effect of ultrasonic radiation to certain places by providing the sources with soundproof casings, half-casings, shields, etc.;

— locating such equipment in separate rooms and chambers;

— systems of interlocking and protection which enable the operator to automatically cut off the source if the soundproofing fails;

— limiting the number of persons exposed to excessive ultrasonic radiation;

— lagging, as far as practicable, the interior surfaces with sound-absorbing materials.

The organizational and preventive measures include instruction of the personnel as regards the character of ultrasonic action on the human body and protective countermeasures available to the workers, the adoption of rational length of work and rest periods, use of personal protective equipment.

Noisy processes and equipment, such as ultrasonic baths and magnetostrictive convertors, should be properly isolated by enclosing them in 1-2 mm steel casings which also incorporate the cooling devices. The sound-proofing effect of the casing can be improved by coating it with roofing paper, rubber and special plastic materials along the perimeter of the casing. All joints in the casing should be properly sealed with rubber, well secured in position by specialized locking devices, and isolated from the bath and the floor with a 5 mm thick rubber lining.

Half-casings can also be useful for ultrasonic baths (in short-time flow(-sheet) processes or under the necessity of constant supervision). The area of the sound-absorbing lagging of the inner casing surfaces should be 15 times that of the open area. The operators working in cabins should be given personal protective devices (earmuffs and plugs).

Technical specifications for industrial equipment include ultrasonic characteristics, such as sound pressure levels in three-line bands of the adopted range of frequencies measured at four specified points over the outlines of equipment at a distance of not more than 1 m from one another, 1.5 m high above the floor, 0.5 m to the equipment outer surface and not less than 2 m to the reflecting surfaces.

Instrumentation. The levels of ultrasonic radiation can be measured by ultrasonic detectors and devices for the measurement and detection of ultrasonic waves. Such devices can be mechanical, electrical, thermal, or optical in nature.

CHAPTER 6

Electromagnetic Radiation: Health Hazards and Protection

High-frequency electromagnetic radiation enjoys a wide range of use in many branches of the economy. In manufacturing industrier its applications include industrial process heating of metals fos melting, hardening, forging, pressing and other metal-working processes, and heat-treatment of non-metal materials for drying, cementing, baking or sintering processes.

The application of radio-frequency (r.f.) currents has increased the rate of production, improved quality of industrial products, facilitated mechanization and automation of industrial processes. The use of electricity for industrial process heating is continuously growing. In most cases it directly competes with gas and oil. In many instances the ease of control and other factors have led to electricity being preferred while in others the qualities of electric heating have made it the only choice. The major difference between electrical heating and gas or oil is that heat can be generated within the body of the workpiece; it does not need to be conducted from the surface and therefore through-heating is possible. Other factors in favor of electric heating are high heating rates and the possibility of using temperatures higher than those which can be attained with gas or oil.

The use of r.f. induction heating in melting and heating industrial processes has sharply reduced pollution of the industrial environment, minimized time and length of exposure of workers to radiant heat during their working hours, and reduced labor intensity and cost of production.

The application of electromagnetic radiation in the range of radio-frequencies in electric heating installations has undoubtedly its economic advantage. However, a systematic exposure to an electromagnetic environment is harmful to health and may be conducive to occupational disorders and functional changes in the nervous, cardiovascular and endocrine systems of the human body.

6.1. ELECTROMAGNETIC FIELD

It is customarily stated that a wire carrying an electric current is surrounded by a magnetic field where lines of force are circles with the wire as their axis. This implies that the magnetic field is directly traceable to the moving electricity in the wire. There is, however, another aspect of the matter. Each electric particle projects into space a field of electric force, and as the particles move along the wire the lines of force move with them. It is the motion of these lines of electric force that sets up the magnetic field transverse to them (the theory of Maxwell). More generally, a variable electric field is always accompanied by a magnetic field, and conversely, a variable magnetic field is accompanied by an electric field. The joint interplay of electric and magnetic forces described is what is called an electromagnetic field, and is considered to have its own objective existance in space. An essential feature of the theory is that this process, whatever it is, represents a flow of energy at right angles to both electric and magnetic components when the fields vary with time. Electromagnetic radiation is, on this theory, the propagation of electric and magnetic stresses (disturbances) through space with the speed of light. When an electric charge is set into motion, it builds about itself an electromagnetic field and this implies a distribution of energy throughout space. The acceleration of the electric charge produces a disturbance travelling in space and calls the electromagnetic wave comprising an electric field at right angles to a magnetic field, both moving at the same velocity in a direction normal to the plane containing the two fields. Light waves and the waves used in radio are of this nature.

Radio frequency (r.f.) is a frequency at which coherent electromagnetic radiation of energy is useful for communication purposes.

The applications of r.f. electromagnetic waves in manufacturing industries range over a large field. Radio waves are used in induction heating and dielectric heating, automation and control to reduce or eliminate the labor in labor-intensive large-scale processes where the advantages of radio waves are considerable. It is widely used in industrial environment with a high degree of pollution, the probability of excessive vibration, high ambient temperatures and a lack of skilled maintenance. Electromagnetic devices are often part of a complex production process where reliability must be high.

Use is often made of electromagnetic waves of high-frequency (HF), ultra-high frequency (UHF) and super-high frequency (SHF) within the following ranges and wavelengths:

Radiation	HF	UHF	SHF
Wavelength, cm . .	10 000-1 000	100-10	10-1
Frequency, Hz . . .	3×10^6-3×10^7	3×10^8-3×10^9	3×10^9-3×10^{10}

Electromagnetic field is characterized by electric field strength (E) and magnetic field strength (H). In the HF and UHF range both electric field strength and magnetic field strength due to the long wave can be measured separately. Electric field strength is measured in volts per meter (V/m), and magnetic field strength in amperes per meter (A/m). In the SHF range, short waves form a unified electromagnetic field where intensity is expressed as power density in watts per square meter (W/m^2).

At the medium and high-frequency range, induction heating is used for through-heating of small billets, prior to rolling or forging, and for upset forging in the general engineering industry.

Electromagnetic induction is the production of an electromotive force in a circuit by a change in the magnetic flux linking with that circuit.

In many applications, especially in those where through-heating is involved, the source of radiation in induction billet heaters is a work coil or a series of such coils through which the billet is transported, being heated as it travels. The r.f. dielectrical heating generators use circuit work capacitors or a series of such capacitors.

Induction heating relies on the Faraday effect. The material to be heated, which must be an electrical conductor, is placed inside a work coil supplied with a current at the appropriate frequency. The work coil current creates a magnetic field causing a current to flow in the workpiece. For a given material the current penetration depth and therefore the heating depth can be controlled by varying the frequency. When induction techniques are used for metal melting or through-heating the frequency is kept low in an attempt to achieve uniformity, but if surface heating only is required the frequency must be high. The deeper layers are heated due to heat conduction from the surface layer. This method is inapplicable to the heating of dielectric materials as the large currents needed to heat a dielectric require higher frequencies. For dielectrical heating in the r.f. range the design principles used for the power source are similar to those involved in r.f. induction heating although circuit techniques must be adapted to take into account the higher frequencies used.

When a non-conducting material is placed in an electric field there is a movement of the electric charges in the material such that they tend to align themselves with the field. If the field is alternating this alignment takes place continuously as the direction of the field is changed, and is accompanied by the generation of heat within the body of the material. To achieve through-heating a non-conducting material is placed in a variable electromagnetic field between metal plates (electrodes) to which a source is applied.

6.2. HEALTH HAZARDS INHERENT IN ELECTROMAGNETIC FIELD

The effect on man of r.f. electromagnetic radiation of high intensity is associated with partial absorption of r.f. wave energy passing through the human body which causes heat and produces, directly or indirectly, ions. As heating takes place, blood circulation increases. This prevents tissues from local overheating. Certain parts of the body (brain, eye, kidney, the innermost parts, i.e. bowels and the tests) are very sensitive to such overheating. If the adaptation mechanism fails, excess heat is not dissipated and the body temperature rises.

The electric conduction in tissues is proportional to the amount of tissue fluid; the highest electrical conduction occurs in the blood and muscles, the lowest in fatty tissues. The thickness of the adipose deposits in the tissues influences the degree of reflection of the electromagnetic waves from the human body. Adiposis in the brain and spinal marrow is negligible, and it never occurs in the human eye, and hence these organs are most sensitive to electromagnetic radiation.

Long and systematic exposure of persons to electromagnetic radiation of various frequencies and intensity in excess of the maximum permissible limits may cause functional changes in the body particularly in the central nervous system. Other symptoms of the changes are headaches, insomnia, rapid fatigue, irritability, and many other conditions.

Apart from fundamental disorders, irreversible changes, such as inhibition of reflex reactions, hypotension, reduction of systole contraction, blood chemistry changes, lenticular opacity (eye cataract) may also occur in the body.

The degree of effect on man exposured to electromagnetic fields depends on the intensity of radiation, duration, distance to the source and individual sensitivity of the person. Persons suffering from hypertension, stenocardia, physiological and chronic hypotention, organic disorders of the central nervous system and eye cataract should not be employed or work under the conditions where electromagnetic fields are unavoidable.

6.3. PERMISSIBLE LIMITS OF ELECTROMAGNETIC RADIATION

The Unified Sanitary Rules for Work with Electromagnetic Radiation Sources is the basic standard regulatory document used in industry. Depending on wavelength this standard regulation gives different permissible limits of radiation for HF and SHF ranges.

Electromagnetic waves propagating in a medium carry a certain amount of energy which is characterized by power density (W/m^2)

$$W = \lambda_2 (\varepsilon E^2 - \mu H^2)$$

where E and H are the electric and magnetic field strength, V/m and A/m, respectively; ε is the permittivity of the medium, F/m; μ is the permeability of the medium, H/m; λ is the wave length, m. The character of propagation and the properties of an electromagnetic field depend on the frequency. Three zones (wave zone, diffraction zone, and induction zone) are distinguished, depending on the distance to the source.

The induction zone (the near zone) lies at the distance $R \leqslant \lambda/2\pi$. The strength of electric and magnetic fields within this zone depends on the type of the radiation source.

The wave zone (the far zone) is at the distance $R \gg \lambda/2\pi$ if $R \gg D^2\lambda$ where D is the geometric size of the source. Within this zone the electric and magnetic components of the field are interrelated by the universal dependence $E = 377H$. The field propagates in the form of spherical waves and the energy density can be calculated through E or through H. The effectiveness of the field within the wave zone is estimated through power density in W/m^2:

Table 19

Electric field strength, V/m			Magnetic field strength, A/m		
frequency range, MHz	wavelength, m	MPL	frequency range, MHz	wavelength, m	MPL
HF range (long, medium and short waves)					
0.06-3	5 000-100	50	0.06-1-5	5 000-200	5
3-30	100-10	20			
UHF range (ultrashort waves)					
30-50	10-6	10	30-50	10-6	0.3
50-300	6-1	5			

$$\sigma = E^2/377 = 377H^2$$

In accordance with the above standard regulation, electromagnetic field (EMF) in the 60 kHz—300 MHz range should be assessed through the strength of its components, and in the frequency range from 300 MHz to 300 GHz, through energy density.

Table 20

Power density		Exposure duration	Note
W/m²	μW/cm²		
A. Invariable parameters of electromagnetic radiation			
From 0.1	Up to 10	8 h	—
From 0.1 to 1.0	From 10 to 100	Not more than 2 h	For the rest of the working day power density should not exceed 0.1 W/m² (10 μW/cm²)
From 1.0 to 10.0	From 100 to 1 000	Not more than 20 minutes	Goggles are obligatory; for the rest of the working day power density should not exceed 0.1 W/m² (10 μW/cm²)
B. Variable parameters of EMF (rotary and scanning antenna)			
Up to 0.1	Up to 100	8 h	—
From 1.0 to 10.0	From 100 to 1 000	Not more than 2 h	For the rest of the working day power density should not exceed 1 W/m² (100 μW)cm²)

Note. With X-rays at workplaces or at high air temperatures (above 28°C) the MPL should not exceed 0.1 W/m² (10 μW/cm²) during 8 h; 1.0 W/m² (100 μW/cm²) for 2h, and 0.1 W/m² (10 μW/cm²), for the rest of the working day. The X-ray exposure dose for the personnel should not exceed the values laid down by the radiation protection standard.

The standard sets maximum permissible limits (MPL) for the strength of the electric and magnetic field components for the work with SHF sources. These limits are different for radiations having constant and variable characteristics (Tables 19 and 20).

6.4. SOME PRACTICAL APPLICATIONS OF ELECTROMAGNETIC RADIATION PROTECTION PRINCIPLES

There is a number of general principles to follow in planning for a safe and efficient protection, and in ensuring electromagnetic compatibility, i.e. the capability of equipment and systems to be operated in the intended operational electromagnetic environment at desired levels of frequency. Here are some examples:

reduce the EMF intensity and energy flux density;
provide protected screens or enclosures to workplaces;
provide adequate space between workplaces and EMF sources;
provide protected location for the EMF sources;

adopt suitable levels of efficiency for equipment and adequate work schedules for the personnel;

ensure, where necessary, means of signalling and alarm (visual, sound, etc.);

provide personal protective devices for the workers, etc.

The reduction of intensity and energy density can be achieved by ensuring matched loads and using energy absorption devices. Protected enclosures, shields and screens use the principle of reflection

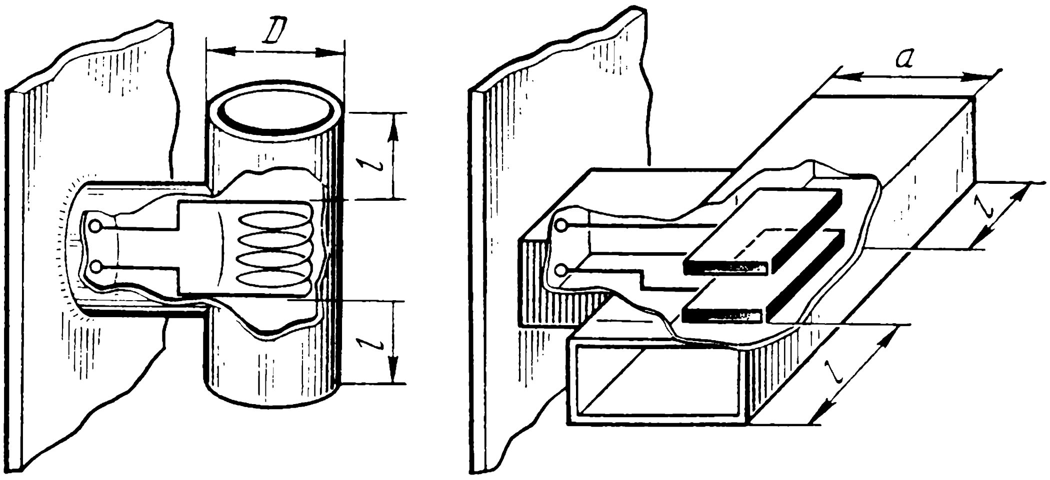

Fig. 55. Shielding of HF sources

and absorption of radiated energy. Metals are highly effective in reflecting and absorbing electromagnetic waves. A metal enclosure, such as a casing or jacket, excludes the possibility for EMF to penetrate outside its confines and hence from the room in which it is installed (Fig. 55). Shielding covers and screening devices are usually made from materials of high electric conduction (steel, copper, aluminium or tin). Normally they consist of metal sheets 0.5 mm thick or are 4 × 4 mm wire screens, or perforated covers. Small openings in an enclosure intended to receive the controls are protected with 4 × 4 mm wire screens. All screens and metal shields are grounded. Electromagnetic radiation protection of induction heating units can be made separately for each unit part (for the generating, or primary, contour, and for the working contour), and singly for the whole unit.

The degree of reduction of electromagnetic radiation by shielding a HF source is characterized by the depth of EMF penetration in to the shield material whose thickness must be larger than the value of the EMF penetration depth.

The EMF penetration depth, δ, into the shield material in which the field is reduced by $e = 2.718$ times is determined by the formula

$$\delta = 1/\sqrt{\mu\sigma\pi f}$$

where μ is the permeability of shield material, H/m; σ is the specific conductivity of shield material, S/m; f is the frequency, Hz.

The efficiency of a continuous shielding must satisfy the inequality

$$E > l^{d/\delta}$$

where d is the shield thickness, mm.

The larger the value of $\mu\sigma f$, the smaller the penetration depth and, consequently, the thinner the shield.

Usually the penetration depth of high- and super-high frequency electromagnetic radiation is small (less than a millimeter) and, therefore, the thickness is selected proceeding from design considerations. In the case where the reflected electromagnetic waves may affect the efficiency of the operating unit, the protective shield is faced or lined with an absorbing material or is made from special-purpose materials (sheets of rubber with specialized fillers, etc.).

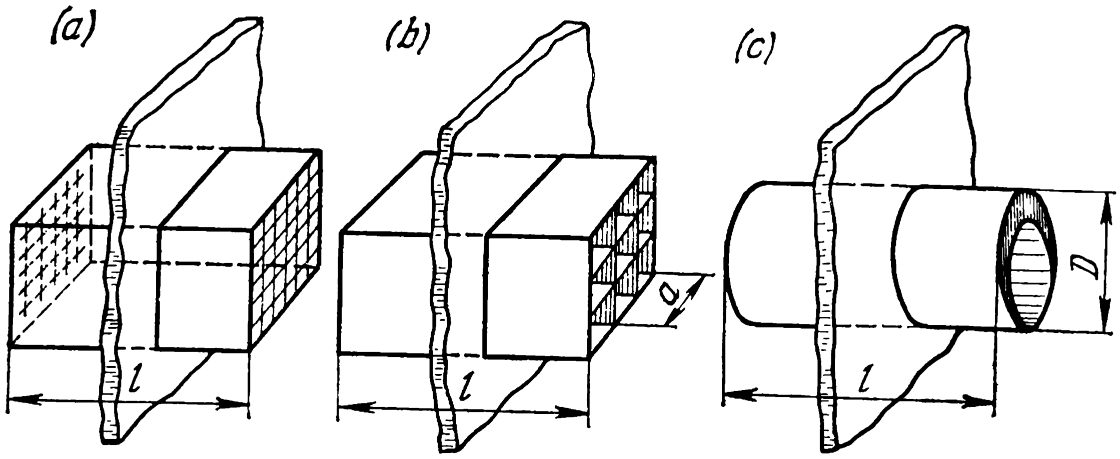

Fig. 56. Screening of peepholes and airholes
(*a*) double-screen box; (*b*) rectangular grill; (*c*) pipe

Bulk metal shields are reliable means of protection against the effect of HF sources. Wire screens are inferior and are used basically for the purpose of reducing the HF power density and also where visual observation of the unit is an essential factor.

Elastic screens (made of special-purpose metallic mesh-based cloth) are used for covers, blinds, different protective clothes, etc.

Sheet glass coated with a transparent film of tin dioxide is also used for shields to reduce electromagnetic radiation levels.

A complete coverage where practicable can be effected by enclosing a HF source in a protected room or chamber, with the source controlled remotedly, or by shielding all its units or where the working part cannot be shielded for technological reasons, by protecting only the HF generating unit of the source with movable metal screens.

Peep-holes in enclosures or chambers are protected with metallic mesh or with glass coated with a specialized screening film (Fig. 56).

High-frequency generators should be installed in rooms that

satisfy degree I and II requirements of fire-resistance; power generators in soundproof rooms or enclosures. Room area should not be less than 25 m^2 for HF sources of up to 30 kW, and should be more than 40 m^2 for HF generators of more than 30 kW power, with least two meters of space between the units.

Rooms incorporating HF sources intended for heat-treating operations are not to be shielded since screening renders the working conditions inconvenient.

To ensure electromagnetic compatibility of equipment or systems the influence of one source on the other should be eliminated during the planning operations by providing adequate space between the sources or equipment pieces. Electric wires, cables, bus-bars and other current-carrying parts should be guarded or made overhead, and protected from heating. Starting devices (also knife-switches, automatic circuit breakers, etc.) should have a visible connection to the mains. General ventilation in rooms should have exhaust openings in the upper portions and the plenum openings in the work zone quarters of the room enclosure. Local exhaust ventilation should be installed where harmful releases from HF sources may present a hazard to human health, with structural elements made from non-metal materials (asbestos-cement, fabric laminate, etc.). Storage or presence of metal objects in HF source rooms, unless necessary for operation, should be avoided to eliminate secondary electromagnetic phenomena due to r.f. wave reflection.

Control leads in high-frequency source are brought out to control panel mounted on the shield face, or to a control board installed outside the enclosure to face the operator (furnaceman). All openings and holes in the enclosure or shield necessary for the controls (handles, fly-wheel axis, wires, etc.) are protected to eliminate EMF penetration. In the case where the control panel is common for several workplaces, each workplace must have an emergency pushbutton to cut off power supply in case of trouble. Two signal lamps are obligatory for a control panel of any HF source; the green lamp showing that the source contour is ready to take load from the anodic transformer, the red lamp indicating that the anodic transformer is on. Metal parts of a HF unit and the secondary windings of the heating contour must be grounded to ensure electric safety and prevent accidents from electric shock in the case when these parts may, through fault or negligence, become live. The grounding bars near the oscillatory contours should not form closed contours to avoid induction heating and increase of electric resistance of the bars.

During the adjustment or maintenance operations performed in an electromagnetic environment the operators should wear personal protective equipment, such as metallized shields, hoods and suits of metallized cotton cloth, special radiation-reflecting goggles that must fit tight to the face to protect the eye.

6.5. INSTRUMENTATION

To estimate electromagnetic radiation intensity in close vicinity of HF sources, measurements of electric and magnetic field strength

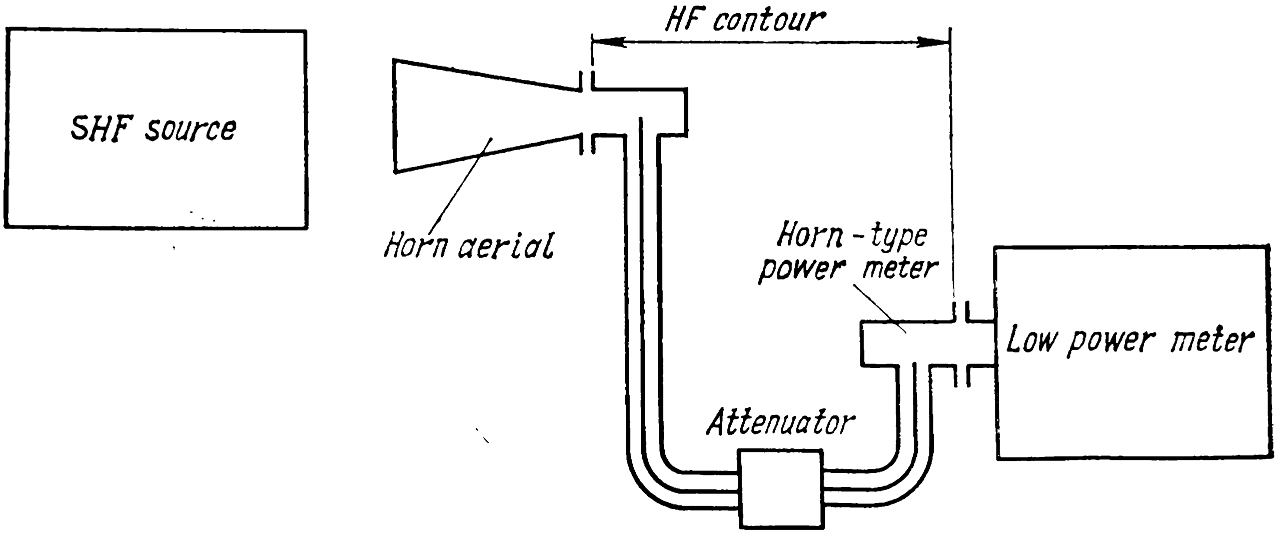

Fig. 57. A schematic for EMF measurement

are made separately. It is necessary because an electromagnetic field in the induction zone is a totality of independent electric and magnetic fields (Fig. 57). The electric or magnetic field strength at a given location results from the passage of radio waves. In the case of a sinusoidal wave, the root-mean-square (rms) value is commonly used. Unless otherwise stated, it is taken in the direction of maximum.

The principal instrument for measuring the intensity of electromagnetic fields is the radio-field strength meter, a device consisting of an amplifier, dipole and frame antennas, and a voltage divider. The device measures the electric field strength in the frequency range from 50 Hz to 100 kHz and 100-30 MHz, and magnetic field strength at frequencies from 100 kHz to 1.5 MHz. The device is calibrated using the range of the working frequencies to give readings of the effective field intensities from 5 to 1 000 V/m for the electric field component, and from 0.5 to 300 A/m for the magnetic field compo-

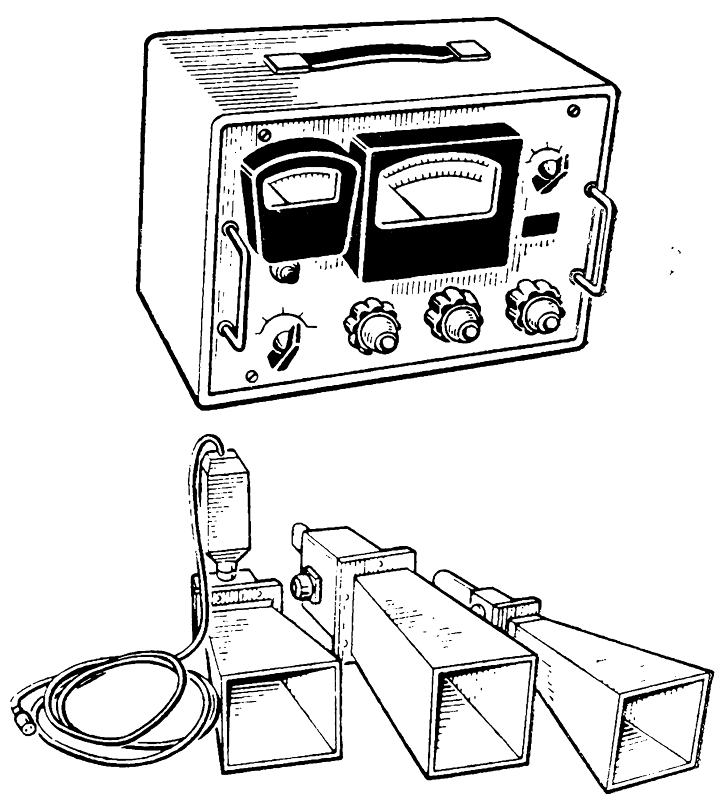

Fig. 58. A device for measuring power density in the SHF range

nent. The error of measurement does not exceed 20%. The antenna is placed in the electromagnetic field to be measured, and its position is varied until the scale gives a maximum reading.

Power densities in the UHF and SHF ranges are measured largerly by the power meter, a device shown in Fig. 58.

6.6. LASER RADIATION PROTECTION

Industrial applications of lasers, i.e. optical quantum generators at present include materials processing, electronics and other industries, medicine, metrology, non-destructive testing, printing applications, and promise to rapidly expand further as the potential advantages of the laser are economically attractive (Fig. 59). The use of lasers for materials processing depends on the very high power densities or energy densities (in the case of pulsed lasers) available in focused laser beams, by which all known materials can be vaporized. However vaporization is not the only process of importance in materials processing using lasers. In welding, for example, it is important to keep the power density low to avoid vaporization. In cutting materials, the laser is used merely as a concentrated heat source. The most intensive use of lasers in the electronic industry is in the trimming of thin-film resistors to tight tolerances by selective removal of material. Another application is for scribing semiconductor slices into dice. Lasers are used in the drilling of very hard refractory materials, such as ruby and diamond.

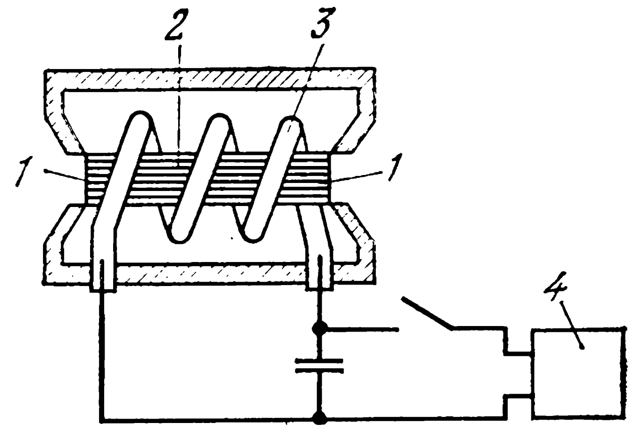

Fig. 59. A pulsed ruby laser
1 – resonator; 2 – ruby crystal; 3 – pump lamp; 4 – rectifier

Laser emissions embrace almost the entire range of electromagnetic waves, from ultra-violet to infrared regions of the spectrum. A focused laser beam is extremely narrow (the angle of divergence is less than 1′), which permits high power and energy densities to be attained readily. Power density of a laser may reach a value of 10^{11}-10^{14} W/cm^2, i.e. much higher than needed to vaporize the hardest known materials (10^9 W/cm^2).

In contact with biological tissues the high energy flux from lasers may cause serious damage to the health of persons operating laser installations. Laser emissions may disrupt the function of the central nervous and cardiovascular systems, cause damage to the skin, etc. Irradiation may cause coagulation of the blood, leucolysis and ery-

throcytolysis. Other undesirable symptoms are rapid fatigue, headache, insomnia, etc.

The gas-discharge impulse tubes, continuous light tubes used in lasers for energy sources are themselves factors of hazard, and call for adequate precautions.

The character and degree of harmful effect of laser beams on the human body depend on the direction of beam, wavelength, power of emission, nature of pulses and their frequency. The energy emitted by the laser is absorbed by the body and is dissipated into heat energy. Absorption capacity of different tissues is different. Thus, fatty tissues do not absorb energy while those of the eye are extremely sensitive to radiation.

The health safety standards lay down the maximum permissible limits of radiation intensity for the cornea irradiation, which are safe for the retina, the most sensitive part of the eye. Thus, the maximum permissible level of energy density is 1×10^{-8}-$2 \times \times 10^{-8}$ J/cm^2 for pulsed ruby lasers and 1×10^{-7}-2×10^{-7} J/cm^2 for pulsed Nd (neodymium) lasers, and 1×10^{-6} J/cm^2 for c.w. (continuous wave) helium-argon (He-Ne) lasers. Protection measures include guards and danger signs to keep persons away from zones of laser radiation hazard.

Other safety measures include the provision of separate special-purpose rooms for laser installations which should be located to face a thick fire resistant wall. The surface finishing of the rooms should be made so as to ensure a minimum reflectivity. Equipment surfaces should not be brought or have brought parts to avoid incident-light reflection. Lighting should provide for a high level of illuminance to keep the eye pupil permanently miotic. Automation and remote control of the laser-based operations are also an important safety precaution.

Personal protection devices include goggles equipped with filters hand shields and blinds, suits and gloves. Calorimetric and photometric methods are realized with the use of appropriate instruments.

CHAPTER 7

Ionizing Radiation: Health Hazards and Their Prevention

At the present day countless branches of industry are affected by the applications of X-rays and the use of radiations and for this reason are directly concerned with the problems of radiation or radiological protection. To start with, these are the industries engaged in mining, treating and processing radioactive ores, radiometallurgical and radiochemical industries, nuclear power stations, research establishments, and all sorts of industrial plants that use radioactive substances particularly radioisotopes and X-ray appliances. Secondly, the medical applications of ionizing radiations raise an acute problem of protection against occupational irradiation. The production of electricity from nuclear energy is also of a considerable interest to the economy.

Ionizing radiations have a host of industrial and other applications outside the basic atomic industries and nuclear power stations. The by-products of these industries, i.e. radioisotopes which with X-ray apparatus constitute the principal sources of radiations used in manufacturing industries for research, testing or production purposes, are now available in quantity. They are used in industry, for example, in the non-destructive testing of materials, thickness and level gaging; flaw detection; as tracers and static eliminators; in structural analysis; for radioactive tagging of materials or objects; the luminizing of dials, and in many other ways. The electron bombardment of metal surfaces was found effective in improving the quality and imparting certain useful qualities to the irradiated material. The industrial applications of radioactive substances have introduced into ordinary industrial establishments the special potential dangers that go with the use of ionizing radiations.

Exposure to radiations may cause serious damage and lead to diseases, such as radiation sickness, leukemia, malignant tumors, skin disease, etc. Radioactive ionization may cause genetic changes that may result in pathological heredity. The effect of radioactive emissions on the body is not perceived until the results manifest

themselves in a pathological condition. The consequences may be complete or partial disability, and even fatal outcomes.

With adequate protection, the observance of safety precautions and instructions, and proper organization of labor the use of radioactive sources is safe for the personnel employed at an undertaking that uses radiations.

7.1. DEFINITIONS

Radioactivity is spontaneous nuclear disintegration with emission of corpuscular or electromagnetic radiations. There are three main types of radiation that can originate in a nucleus: alpha (α), beta (β), and gamma (γ) radiation. The principal types of radioactivity thus are α-disintegration, β-decay, and izomeric transition. To be considered as radioactive a process must have a measurable life-time. Radiations emitted within a time too short for measurement are called prompt; however, prompt radiations, including γ-rays, X-rays are often associated with radioactive disintegration, since their emission may follow the primary radioactive process.

Radiation is called ionizing if when passing through matter it results in the formation of positively- or negatively-charged ions, the changes of the individual ions being due to the gain or loss of one or more electrons from the outer orbits of one or more of their atoms. The ionizing radiations are X-rays, radio and γ-rays, α-rays, β-rays, stream of neutrons, and other nuclear particles, and cosmic rays.

Alpha-ray is a stream of alpha (α) particles composed of two protons and two neutrons and emitted by a heavy nucleus with velocities from 1.4 to 2.0×10^9 cm/s, causing considerable ionization of the air along their path. They have been identified as the nuclei of helium atoms which are positively charged on account of each having lost two electrons. Alpha particles are the heaviest of the particles emitted by radioactive substances, and can possess only discrete amount of energy. The penetrating power of α-rays is relatively poor.

Beta-ray is a stream of beta (β) particles which are negative electrons or positive electrons (positrons) emitted by nuclei of radioactive substances undergoing β-disintegration, and moving with velocities of up to 90% of light velocity. Beta-particles are much smaller than α-particles and therefore have greater penetrating powers.

Gamma-ray is a quantum of electromagnetic radiation emitted by a nucleus as a result of a quantum transition between two energy levels of the nucleus during nuclear reactions or radioactive decay. The ability to penetrate matter is high, and the ionizing power, poor.

Roentgen or X-ray is a high-frequency electromagnetic radiation of wavelengths less than about 100 Å produced when electrons accel-

erated in a vacuum, strike a target and lose kinetic energy in passing through the strong electric fields surrounding the target nuclei. Their capacity for penetrating considerable thicknesses of solids is very high.

Gamma radiation is electromagnetic in nature and has, therefore, no charge or mass. Its wavelength is much shorter than that of light or radiowaves, and is similar to that of X-rays. The distinction between γ-rays and X-rays is that γ-rays are produced within the nucleus while X-rays are produced by the transition of an electron from an outer to an inner orbit.

Neutron radiation was discovered in 1932 as a result of bombarding light elements with α-particles. Because neutrons are uncharged they do not cause direct ionization, and may travel large distances in materials having a high atomic number. The most efficient materials for shielding against neutron emission are those having light nuclei; these reduce the energy of neutrons much more rapidly than heavier materials. Examples of efficient shielding materials are water, the hydrocarbons and graphite.

The quantity called the absorbed radiation dose which characterizes the total amount of radiant energy absorbed by a unit mass of substance is used commonly for a quantitative assessment of the effect of any ionizing radiation

$$D_{abs} = W/m$$

where W is the ionizing radiation energy absorbed by the substance, J, and m is the mass of the irradiation substance, kg. In the SI, the unit of radiation dose is a joule per kilogram (J/kg), that is, a radiation energy of 1 J transported to a substance 1 kg in mass.

The erg unit of radioactive dose of exposure used in practice is the roentgen (R): 1 R is the amount of gamma- or X-radiation such that the associated corpuscular emission per 0.001293 gram of air produces in the normal air (at a pressure of 101.325 kPa or 760 mm Hg and a temperature of 0°C) ions carrying 1 electrostatic unit of quantity of electricity (charge) of either sign; 1 roentgen (R) = $= 10^3$ milliroentgen (mR) $= 10^6$ microroentgen (μR).

In practical use is also another unit of absorbed radiation dose known as rad, which is equivalent to an energy of 0.01 J that gamma-radiation imparts to 1 kg of irradiated matter: 1 rad = 0.01 J/kg = = 100 erg/g = 1.15 R.

Measuring the dose of radiation by its ionizing capacity has led to the establishment of a quantity called a radiation-exposure dose that characterizes the degree of ionization produced by the roentgen and gamma radiations:

$$D_{exp} = Q/m$$

where Q is the total charge of ions of one sign, C; and m is the mass of air, kg.

The SI unit of radiation-exposure dose is the amount of radiation such that the associated corpuscular emission per 1 kg of dry air produces in the normal air ions carrying a total charge of 1 C of either sign. Since the mass of 1 cm^3 of air is equal to 1.293×10^{-6} g, then, considering the relation between the coulomb and the erg unit of charge, 1 R $= 2.58 \times 10^{-4}$ C/kg, 1 C/kg $= 3.88 \times 10^3$ R.

The dose rate is the intensity of radiation per unit time. The unit of dose rate is a watt per kilogram (W/kg) and a rad per second (rad/s): 1 rad/s = 0.01 W/kg; 1 rad/h $= 2.78 \times 10^{-6}$ W/kg.

The effect of different radiative emissions on live tissues depends on the penetrating and ionizing powers of radiation. The biological effect of a dose of different radiations is different. The term relative biological effectiveness (RBE) has been used to compare the effectiveness of absorbed dose of radiation delivered in different ways. The term RBE dose means the product of the dose in rads and an agreed conventional value of the relative effectiveness (RBE) with regard to a particular form of radiation effect. The attempts to evaluate the hazard from different radiations has led to the establishment of the unit of RBE dose called roentgen-equivalent-man or rem

$$D_{eq} = D_{abs}/k$$

where k is the qualitative factor showing the relation of the biological effect of the given radiation to that produced by X-radiation assumed to be unity. Thus, 1 rem is the dose of any ionizing radiation that will produce the same biological effect as the one produced by 1 roentgen of high-voltage X-radiation.

It will be appropriate here also to mention the physical equivalent for the statements of dose of ionizing radiation not covered by the definition of the roentgen, known as roentgen-equivalent-physical or rep: 1 rep is the dose of gamma-radiation that imparts such an energy to 1 g of substance as to enable it to emit the energy equivalent to the one necessary to ionize 1 g of air. Under standard conditions, 1 rep = 0.09 R = 85 erg/g.

7.2. RADIATION HAZARDS

The wide-scale use of radioactive substances and development of nuclear energy extended the potential risks of irradiation to broader sections of the population and intensified research into the deleterious effects of radiations and the methods of guarding against them.

The effect of ionizing radiations and X-ray exposure is specific in that it passes unnoticed until it manifests itself in an abnormal health condition. Exposure to a radiation usually cause no unpleasant sensation to man and this gives rise to carelessness and negligence as regards safety precautions and, as a result, may lead to serious health damage. The knowledge of the potential risks of radiations is

very important as the radiation hazards are incomparable in their identification to any other known occupational risks. Often, the workers and supervisors (in establishments where the radiative sources are of low or medium activity) do not realize how serious the danger inherent in the work might be and/or are not sufficiently informed of the risks or the precautions to be taken. There is always room for improvement in staff information and education to ensure that the basic principles of protection are understood and applied. In most cases the danger of irradiation which can be external and internal can easily be controlled. Work with unsealed sources of radioactivity entails potential risks of internal irradiation that are generally more serious than those arising from external exposure (sealed sources). Internal irradiation is caused by radioactive substances that enter the body by inhalation, ingestion, or absorption through the skin. In such cases, most dangerous are radioactive isotopes with a long half-life and high intensity. Especially rigid precautions should therefore be taken to prevent such substances from entering and accumulating in the body.

The risk of irradiation resulting in the ionization of the atoms and molecules of the human body constitutes a serious menace to health. The result of ionization is the breakage of nuclear bonds and change of chemical structure of various compounds. This leads to metabolic disorders and other biochemical changes in the live cell. Radiant energy of high intensity and duration may kill separate cells and organs and even cause depth.

Ionizing radiations may inhibit the function of hematogenic organs, disrupt normal coagulation and increase capillary fragility, cause dysfunction of the gastrointestinal tract and cachexia, and reduce the capacity of the body to resist infection. When adequate precautions are not taken, work with radioactive substances may cause radiation injury to the skin; such injuries may be acute or systemic. A systemic injury from irradiation shows up after some time in the form of skin dryness, skin fissure and anabrosis, ulceration, brittleness of the nails and shedding of hair.

Another biological effect of radiation is the radiation burn which shows up as a blister, oedema, and necrosis. Healing of skin ulcerations takes long time; ulcers leave scarring and may give rise to malignant neoplasms. The skin affords good protection against alpha- and soft beta-rays whose penetrating powers are poor. But these radioactive particles may enter the body by inhalation, ingestion (contaminated water, food), and rarely by absorption through the skin. Most serious menace arises from internal radiation with α-particles. They are most harmless with external radiation, but produce high density of ionization when acting internally. Some radioactive substances are externally toxic, their noxious effect sometime is stronger than that of the strongest poisons of plant or animal origin.

It is possible with the existing exposure monitoring techniques (radiation detectors, counters, and dosemeters) to determine anywhere and at any time the dangers of radioactive exposure inherent in work. It should be pointed out, however, that in determining exposure doses the most important information is the data on the amounts of radioactive substances in the body of man and not their concentrations in the working environment. The permissible levels of irradiation should be considered as the maximum allowable doses of irradiation. The radiation protection standard sets maximum permissible limits of radioactive contamination for the skin surface of the personnel, outer surfaces of workrooms, enclosures and transportation means. It should be noted that even negligible radioactive contamination of the above mentioned surfaces during work is fraught with danger of intensive internal irradiation of the human body.

7.3. STANDARDS OF RADIOLOGICAL SAFETY

In this section the following terms have the meaning hereby assigned to them:

—the term "ionizing radiations" means electromagnetic or corpuscular radiation capable of producing ions directly or indirectly in its passage through matter;

—the term "radioactive substance" means any substance which consists of, or contains, any radiative chemical elements, whether natural or artificial;

—the term "sealed source" means any radioactive source of ionizing radiations that is firmly bonded within metals or sealed in a capsule or similar container of adequate mechanical strength so as to prevent dispersion of the active material into the surrounding room or other workplace;

—the term "radiation hazard" means the danger to health arising from exposure to ionizing radiations; it may be due to external radiation or to radiation from radioactive material within the body;

—the term "external radiation" means radiation received by the body from sources external to it;

—the term "internal radiation" means radiation received by the body from sources within it;

—the term "occupied area" means an area which may be occupied by personnel and where a radiation hazard may exist;

—the term "controlled area" means an area in which the personnel occupational exposure to radiation or radiative material is under supervision of a competent person;

—the term "leakage radiation" means all radiation except the useful beam coming from within a protective housing;

—the term "protective housing" means a housing of an X-ray tube or of a sealed source intended to reduce the leakage radiation to a specified level;

—the term "curie" means the quantity of radioactive nuclide in which the number of disintegrations per second is 3.700×10^{10}.

The work with radioactive isotopes and X-rays in industry, the information now available on the biological effect of radiations have made obvious the need for protection against ionizing radiations not only of the persons directly or indirectly associated with such substances but also of a broad section of the population living close to the undertakings that use radiations.

Radiological safety of the staff associated with radioactive sources is ensured by the standardized maximum permissible staff-exposure doses, by use of the various technical precautions which are now highly efficient (screening, shielding, remote control and manipulation, air cleansing, decontamination, etc.), application of time and distance protection, and use of personal protective equipment. Also important is the use of exposure monitoring devices, such as radiation counters, dosimeters, to determine the extent of hazard inherent in the work, and intensity of radiation. It should be pointed out that all protective measures have proved their worth in keeping the staff exposure down to safe levels, but the objective is to protect the workers in such a way that they receive only a fraction of the maximum permissible dose. In this respect it is important that in matters of radiological protection a wide margin of safety should be "built-in" from the very planning stage onwards.

There is a number of regulations regarding safety rules and standard precautions against ionizing radiation of which the principal is the Standard Rules of Radiological Safety. It sets the maximum permissible exposure doses (MPD), the annual absorbed dose which when received by the age of 50 have caused no changes identifiable by modern diagnostic methods to the irradiated person or his progeny.

The degree of damage by internal radiation depends not only on the exposure dose but also on the site in the body, called the critical organ, where the accumulation of deposited radioactive material is highest.

Radiological protection standards lay down maximum permissible doses and concentrations (MPD, MPC) which apply to occupational and non-occupational internal and external exposures, depending on the group of irradiated organs of the body and the category of persons exposed to radiations. These standard values are additional to irradiation doses such as from natural background and medical procedures.

The entire population can be divided into three major categories:

Category A—people within controlled areas who by trade or profession are directly associated with storage, use or manipulation of

sources or equipment producing ionizing radiations, and as such, are likely to be irradiated;

Category B—persons inhabiting localities within occupied areas, and

Category C—general population of localities, areas, regions, and the country as a whole.

Maximum permissible doses of external and internal radiations differ depending on the group of irradiated critical organs or human tissues, which are as follows:

Group I—the whole body, gonads, red bone marrow;

Group II—muscles, thyroid, adipose (fatty) tissue, liver, kidney, spleen, gastrointestinal tract, lungs, eye lens and other organs except those which fall under Groups I and III;

Group III—bone tissue, skin of the hands, forearm, malleolus, and feet.

Table 21 presents maximum permissible doses of internal and external exposure for different groups of critical organs (Category A)

Table 21

Group of critical organs or tissues	MPD, rem	
	3 mon	12 mon
I	3	5
II	8	15
III	15	30

Table 22

Category of persons subject to irradiation	Annual MPD, rem, for groups of critical organs		
	I	II	III
A	5	15	30
B	0.5	1.5	3.0

received during 3 and 12 months. The maximum permissible doses of external and internal radiations for different groups of critical organs and categories of persons subject to irradiation are given in Table 22. In any case the dose received by the whole body by the age of 30 should not exceed 12 MPD. The dose received by Group I organs in persons under Category A should not exceed the MPD, which can be determined by the formula

$$D \leqslant 5\,(N - 18)$$

where D is the absorbed dose, rem; and N is the age, years.

The provisions of the radiological protection regulations apply to both sealed and unsealed radioactive materials and are aimed at preventing the contamination of the open skin, clothes, working surfaces, the ambient air, and the penetration of such substances into the body through inhalation, absorption through the skin, etc.

Radioactive nuclides (isotopes) may be classified in five groups according to their radioactive toxicity:

Group A: Very high toxicity (activity of 3.7 $\times$ 10^3 s^{-1} or 0.1 μc);
Group B: High toxicity (activity of 37 $\times$ 10^3 s^{-1} or 1 μc);
Group C: Moderate toxicity (activity of 370 $\times$ 10^3 s^{-1} or 10 μc);
Group D: Slight toxicity (activity of 3 700 $\times$ 10^3 s^{-1} or 100 μc); and
Group E: Very low toxicity (activity of 37 000 $\times$ 10^3 s^{-1} or 1 000 μc).

In view of extreme diversity of processes carried out with unsealed radioactive sources and the great variety of the resulting risks, workplaces are classified according to the nature of the operations and the physical properties of the substances used, the particular radioactive nuclide, and the quantities used. Installations should be adapted to the hazards of internal and external radiations, with a distinction drawn between two main classes of installations, namely specialized and non-specialized installations.

The classification of operations should distinguish, in increasing order of radiation hazard, between:

(a) storage,
(b) very simple wet operations,
(c) normal operations,
(d) complex wet operations and simple dry operations, and
(e) dry and dusty operations.

Specialized installations are divided into three types of workplace, according to the activity of substances and their relative toxicity:

Type III workplaces are general-purpose chemical laboratories using normal equipment and methods of work with non-volatile and non-emanating substances; other operations require exhaust hoods or glove boxes.

Types I and II workplaces are specialized rooms which must satisfy particular technical and hygienic requirements and include exhaust hoods and glove boxes for work with radioactive substances; if necessary they must be modified or supplemented with due regard to the increased external and internal radiation hazards.

Workplaces under the three types should be reserved exclusively for work with radioactive substances, be isolated from other workplaces as far as practicable, and identified by means of an appropriate and easily recognizable warning sign. Workplaces should be so designed and arranged as to limit the contamination of surfaces and atmosphere, and the open surfaces of the worker's hands and body. Contaminated surfaces may become potential sources of internal and external radiation. The walls and floors of workplaces must be made of smooth and impermeable materials or completely covered with a smooth and impermeable material, with all the interstices effectively sealed. They must be kept clean and clear of obstruction. As far as practicable, the radioactive concentrations in the air of workrooms should be kept by the appropriate system of ventilation

below the maximum permissible values, indicated earlier in this section.

The exposure dose for the external irradiation of the skin can be calculated with good precision; the permissible levels of surface contamination can be defined clearly with due regard to the activity of the substance and the surface area subject to contamination. It is more difficult to determine a safe dose of internal radiation as it depends on many factors that are not easily accountable. The permissible levels of contamination of the skin surface, personal protective devices, workroom and equipment surfaces are not calculated. They are set by the sanitary standards for each type of workplace, and take into account the experience in the storage, use and handling of radioactive materials, the degree of airtightness of process, the effectiveness of detergents, etc.

7.4. IONIZING RADIATION. PROTECTION PRINCIPLES

The provisions of this section apply to industrial establishments where radioactive substances, sealed or unsealed, and equipment capable of producing ionizing radiations, are manipulated, operated or used within controlled areas. As far as practicable, ionizing radiations must be used only within enclosures set apart for the purpose, and which provide, under all operating conditions, adequate protection against useful beam, leakage and scattered radiation for all persons outside enclosures; effective intervals must be provided to prevent any person from entering the room during irradiation, and effective means, which cannot be reset from outside, to prevent or quickly interrupt the irradiation, if such necessity arises.

Suitable collective and individual protective measures must be taken to ensure that the maximum permissible doses, concentrations and body burdens are not exceeded as regards external and, more particularly, internal radiation hazards. The general safety precautions against penetrating radiations rely on the time of exposure, distance to the radiation source, and protective shielding. The time of exposure within dangerous zones should be limited to avoid overexposure of persons in excess of the maximum permissible doses. The intensity of irradiation is inversely proportional to the squared distance to the source. Provision for safe distances may save the cost of protective shielding which sometime is found inconvenient for the operator.

Protective shields (Fig. 60) are available in various designs, and can be stationary, portable, knock-down and table-type shields. The protective power of shields is calculated relying on the laws of attenuation of beams in passing through matter. The thickness of protective shield may be found from reference tables and nomograms.

There is no need to calculate the thickness of shields against α-rays because the penetrating depth of such high-energy particles in matter does not exceed 55 μm. Glass, acrylic plastic material and foil with a thickness of a hundredth fraction of millimeter afford good protection against α-radiation.

The thickness of shield material against β-rays can be determined proceeding from the maximum depth of β-particle penetration in passing through shield materials, and density of such materials.

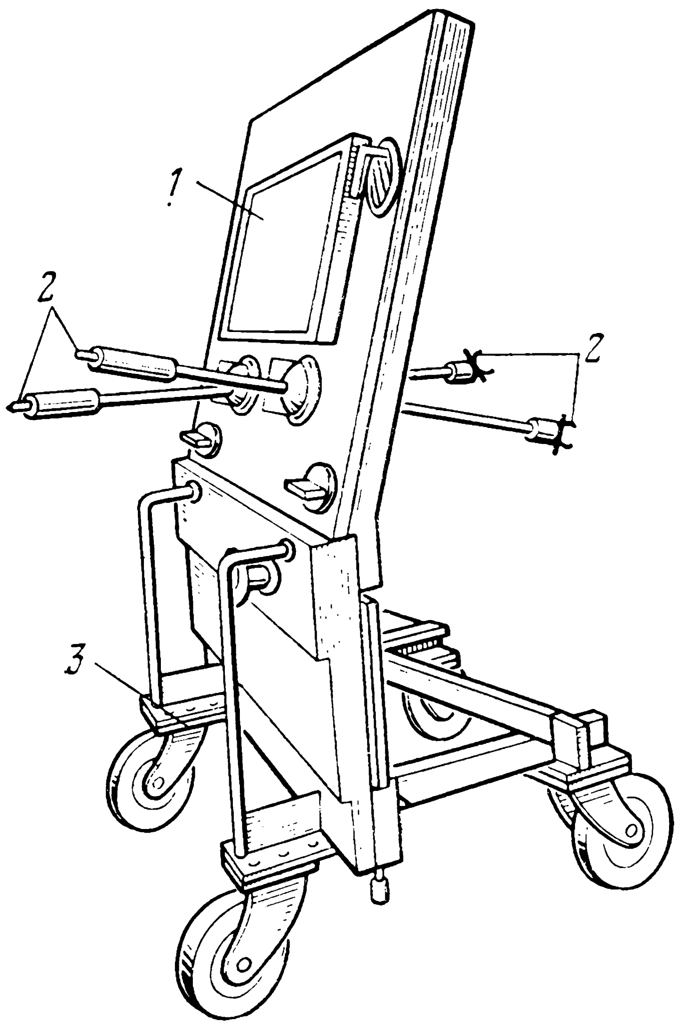

Fig. 60. Portable shield against penetrating radiations

1 — inspection window; 2 — manipulators; 3 — wheeled carriage

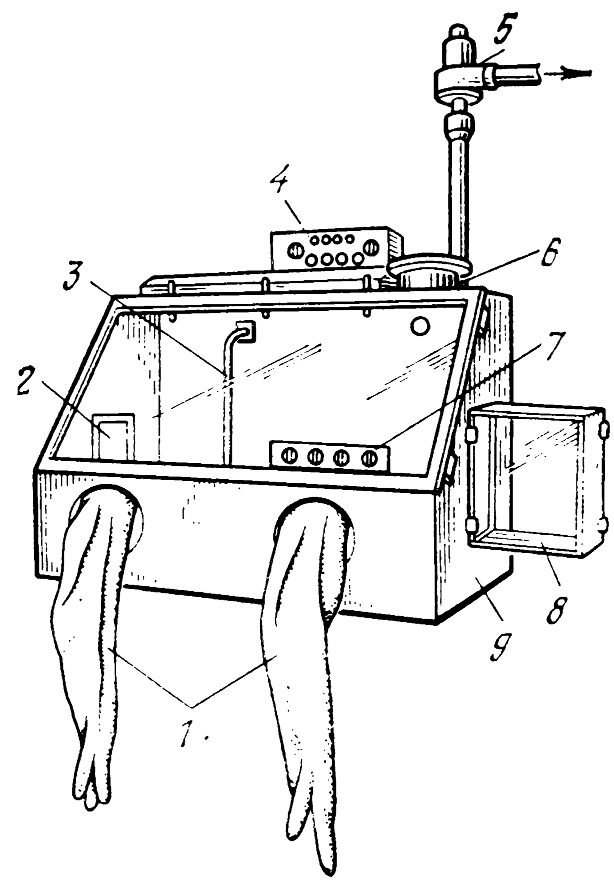

Fig. 61. A table glove box

1 — gloves; 2 — filter-door; 3 — mounting upright; 4 — power source panel; 5 — fan; 6 — filter; 7 — controls; 8 — sluice-door; 9 — casing

Metal elements with a high atomic number and density, such as lead, tungsten, etc., provide effective protection against γ-radiation, although metals of medium density, such as stainless steel, iron, copper alloys, may also be used for such purposes.

By choosing proper materials and the necessary thickness of the shielding devices it is possible to reduce the intensity of external radiation at workplaces to any specified level. It should however be noted that in choosing protection methods, preference should be given to the protection permanently built in the installation rather

than to the use of personal protective devices which are basically supplemental.

Reliability of protective shields in all occupied areas in which radiation hazards are likely to arise should be monitored by using the appropriate dosimetric instruments and devices. The major objective of safety in the operation and use of sealed sources is a dependable protection against external radiation. Thickness gauges, static eliminators and similar devices using sealed sources must be conspicuously and permanently marked so as to warn the personnel of the presence of radioactive material and the need to avoid unnecessary exposure.

Industrial type X-ray installations for radiography, fluoroscopy, diffraction and similar uses of X-rays should have a protective housing of tubes to reduce the leakage radiation when the tube is operating continuously. Where practicable, shields shall be installed close to and surrounding the useful beams to absorb scattered radiation. The X-ray equipment should be installed in enclosures that provide adequate protection, and are fitted with interlocks so as to prevent access to the enclosure during irradiation. Where practicable, effective means must be provided to eliminate the hazard of exposure of the hands and fingers to the useful beams while making adjustments. Effective beam stops or shields must be provided to absorb the useful beams. The most suitable material for shielding is sheet lead or lead rubber. The X-ray apparatus should be installed in dry rooms with wooden flooring, and a ventilation system that is capable of ensuring 3 to 5 air changes per hour.

The standard regulation contains provisions for the use and preparation of unsealed radioactive sources in industry. These provisions apply to all unsealed radioactive sources liable to create not only external but also internal radiation hazard during the preparation, adaptation, use and storage of sources. All processes liable to cause radioactive contamination of the atmosphere should be carried out inside a working space that ensures protection by complete enclosure in a glove box kept at a reduced atmospheric pressure, by partial enclosure, or by exhaust ventilation. The exhaust system must satisfy the general requirements set for industrial ventilation systems and be so constructed as to be easily dismantled for cleaning. It should terminate in the open air at a place satisfying the necessary general requirements after passing through a filtration or recovery plant, if necessary, and so that contaminated air cannot re-enter any occupied area. The requirements of airtightness for the exhaust devices are more rigid than for similar devices in general-purpose laboratories. The velocity of the exhaust air in such airtight enclosures should be maintained not less than 1 m/s, and in Type I and II workplaces not less than 1.5 m/s; reduced atmospheric pressure should be monitored within a value of not less than 200 Pa.

The preparation, adaptation and manipulation of unsealed sources of radiation must be carried out in box enclosures. These are made of acrylic plastics, aluminum, stainless steel, and are equipped with rubber gloves or mechanical arms (Fig. 61). The atmospheric pressure inside the box is kept low, and is continuously monitored with a pressure gauge and a velocity meter. In addition to the dust filters, such glove boxes are equipped with gas and dust-catchers placed behind the filtering units to remove gases or vapors emanated by the radioactive substances. Table exhaust-cabinets consisting of a hermetically sealed glove box, a prechamber and an exhaust branch-pipe are also available. The exhaust hoods and glove boxes are supplemented with all the necessary attachments, such as mechanical or transfer arms, handlers, telechiric devices, slave manipulators and positioners for soldering or cutting of wires, opening of ampules or other types of container, and for various other operations.

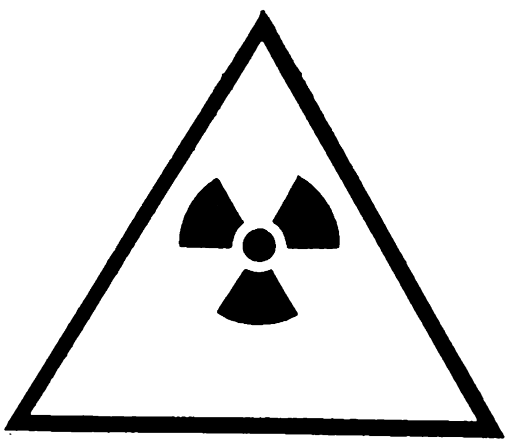

Fig. 62. Radiation danger: a red sign against a yellow background

Workrooms and workplaces reserved particularly for work with radioactive substances should be isolated from other workplaces and be designed so as to include three separate zones. The walls, floors and doors should be made of smooth and impermeable material devoid of pores and cracks. All the room corners are rounded to facilitate decontamination. Separate air supply should be made available in the workrooms for use with the hose-type and air-line protective devices. Dilution ventilation is prohibited.

All areas in which the sources and equipment may give rise to internal radiation hazard must be provided with pedal-operated wash-basins, showers, and hot water supply facilities, if the risks of contamination are serious. The waste-water disposal system should provide for decontamination and recirculation of process water. Disposable paper towels and handkerchiefs must be provided for the persons employed.

Special facilities must be provided for the storage of unsealed radioactive sources to control the external radiation hazard and internal radiation by minimizing the possibility of dispersal of radioactive material. Active materials should be stored in airtight recepticles, such as glass bottles with tight stoppers of rubber, cork or similar materials, sealed glass ampules, aluminum boxes and containers.

Radioactive substances should be transported or handled in locked containers. The walls of such containers should be made sufficiently

thick so that radiation at a specified distance does not exceed the safe values. The material for containers should be mechanically strong, resistant to corrosion, and smooth to facilitate decontamination. All protective receptacles used for the transport or handling of radioactive sources, workroom doors and equipment should be made distinguished by special markings. As far as practicable, use should be made of a pictorial symbol (Fig. 62) to warn about the radiation danger.

7.5. MONITORING AND MEASUREMENTS

Monitoring is periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region, or in a person, as a safety measure for purposes of health protection. Area monitoring is the routine determination of

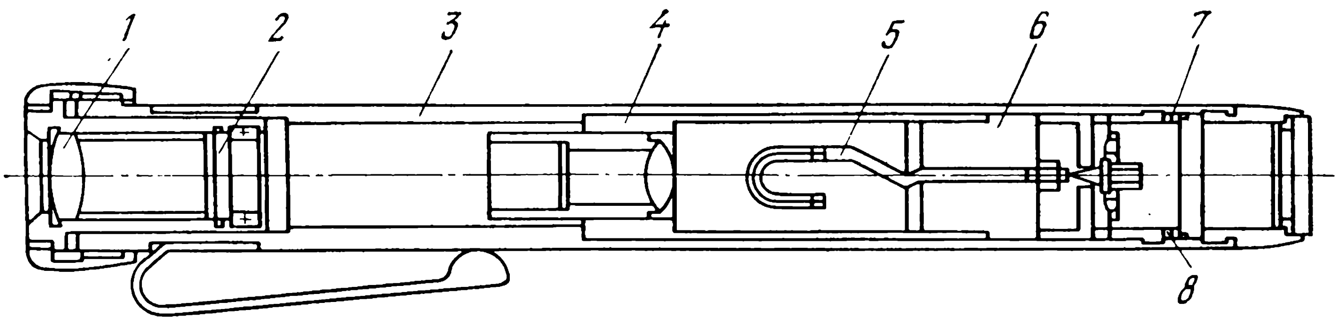

Fig. 63. Pocket ionization chamber or dose-meter
1 — membrane; *2* — aperture; *3* — casing; *4* — ionization chamber; *5* — electroscope; *6* — amber insulator; *7* — eye-piece; *8* — microscope scale

the levels of radiation or of radioactive contamination of any particular area, building, room or equipment. Usage in some laboratories or operations distinguishes between routine monitoring and survey activities. Personal (or personnel) monitoring is the monitoring of any part of an individual, his breath or excretions, or any part of his clothing.

Dosimetric instruments operate relying on the ionization, scintillation and photographic methods of recording. The ionization method is based on the ability of ionized gases to conduct electricity. The scintillation method uses the capacity of certain crystals, gases and solutions to emit flashes of visible light when absorbing the energy of ionizing radiations. The photographic method utilizes the effect of ionizing radiation on photoemulsion.

Area and personal monitoring are carried out by using monitoring devices, fixed or portable, such as (photo)film badges, ionization chambers or dose-meters (Fig. 63), and radiometers. A *radiometer* can be any suitable instrument for detecting and usually also for measuring the radiant energy. The choice of instrument depends on the type of radiation being monitored and the type of monitoring.

If work with radiation sources is associated with a risk of extended radiation, personal radiation detectors must be continuously worn by the persons to indicate and systematically determine the radiation dose received during a particular period (day, week, etc.).

7.6. INDIVIDUAL PROTECTION

Individual protection is considered to be supplemental to the collective protection measures which cover both the design and arrangement of workplaces and the choice of ordinary and special equipment.

Individual protection must comprise:

(a) selection and use of adequate working methods and procedures;

(b) adoption of safe working habits;

(c) provision and use of appropriate tools and facilities; and

(d) provision and use of appropriate protective clothing and devices.

Work without protective clothing in workplaces where radioactive sources are prepared or used must be forbidden. Protective clothing must be adapted to the risks of contamination, and suitably marked. According to the risks, suitable coveralls, head coverings, gloves, tight-clothing suits, impermeable footwear and aprons must be available at workplaces. If the atmospheric contamination cannot be reduced to the maximum permissible levels, effective respirators, hoods or helmets must be provided. All protective clothing must be checked periodically and kept clean. The cleaning of contaminated clothing must be done separately from other clothing by methods which minimize dispersal of contamination. Changing working clothes to outdoor clothes and vice versa must be done in suitable locker rooms adjacent to washrooms so as to avoid any contamination of the outdoor clothes.

Personal protective equipment intended for work with radioactive substances include the means of every-day use such as coveralls, suits, protective footwear, respirator, etc., and special-purpose protective devices, such as isolating suits which can be hose-type and self-contained suits, often called pneumatic suits (Fig. 64).

Pneumatic suits intended for emergency repair work in active zones are designed so as to afford effective protection by isolating the person from the hazardous environment and ensuring maximum environmental comfort for the body. Respirators and hose gas-masks can effectively be used for the protection of the lungs and respiratory organs.

Protective clothing includes coveralls, headcaps, rubber gloves. Specialized overalls, underwear, chlorvinyl aprons, oversleeves and armlets, film coveralls, protective shoewear are to be worn when working with radioactive quantities of more than 10 μc.

Decontamination of controlled areas should be carried out by the smallest practicable number of workers equipped with special clothing. The cleaning appliances must be used solely for cleaning, be decontaminated after use and kept in suitable places.

Special protection provisions include the use of short (290 mm) gloves and long (600 mm) gloves made from latex materials which are easy to decontaminate. Because leather and cloth gloves absorb liquids and dust their use is prohibited. Gloves made of lead rubber equipped with flexible armlets are used for high-intensity radiation operations. The general requirements for gloves is to fit tight to the

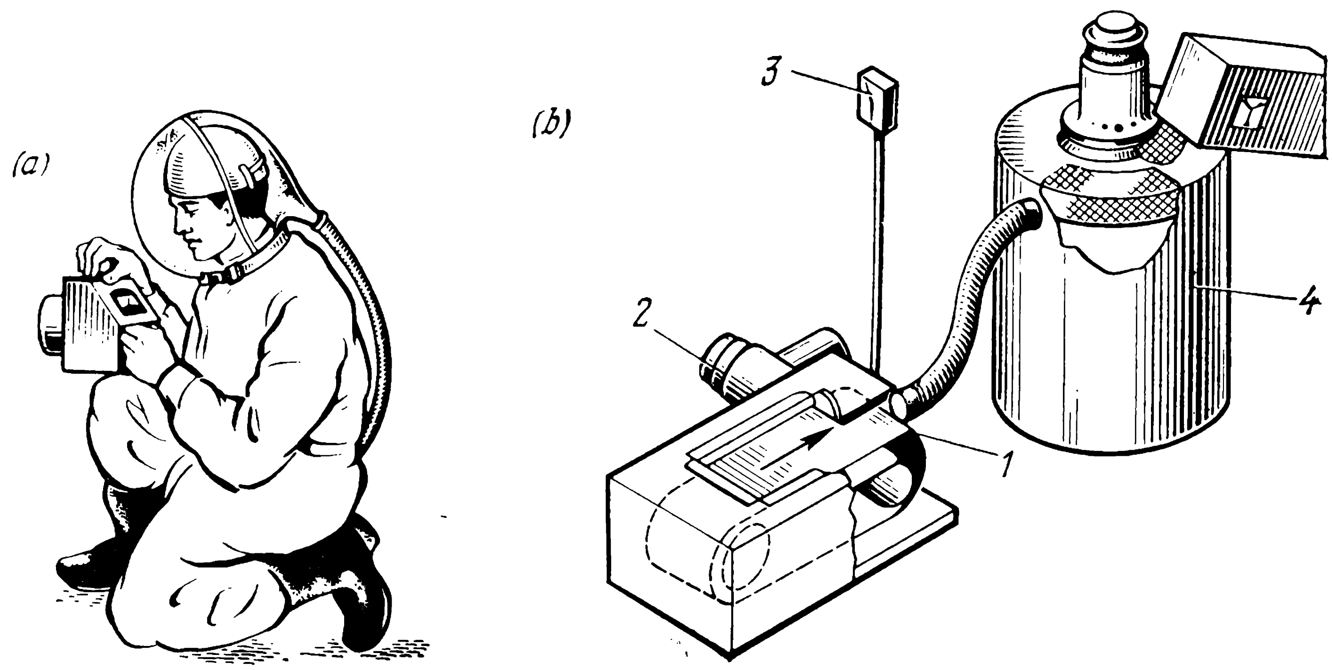

Fig. 64. Personal radiation protective devices
(*a*) pneumatic suits; (*b*) mechanical cleaner; *1* — circular rubber belt; *2* — electric drive motor; *3* — switch; *4* — dust-cleaner

hands and provide freedom of movement for the fingers. Before removal, the gloves must be washed using soap and water, dried and kept in special places wrapped in cloth or put on a dummy stand. Periodically gloves are checked for adequacy.

Goggles with normal glass or acrylic plastic lenses afford adequate protection of the eye against soft β- and α-rays. Silicate glass or acrylic plastic 2.2-2.5 mm thick glasses are normally used for the eye protection from higher energy β-radiation. Goggles with lead glass or tungsten phosphate glass are used to protect the eye from γ-rays, and cadmium borosilicate glass or glass containing fluorine compounds, to protect from neutron radiation. Lead glass thickness is determined from the consideration of convenience and mass. It is desirable that protective goggles are not heavy to wear, fit tight to the face to protect the eye from radioactive dust and vapors; for the purpose they are attached to or made part of rubber or leather face-piece.

CHAPTER 8

Electrical Accident Prevention

The electrification of amber by rubbing with wool or fur was observed many centuries ago. Not until the work of Volta late in the 18th century that electricity was recognized, but investigations and applications of electrical currents were among the most brilliant features of the 19th century physics. However, even in the 1890s physicists were still asking "What is electricity?" At the turn of the 20th century electricity became widespread, and today the practical applications of electric energy are numberless. Industrial uses of electricity have changed a mechanically operated factory, railway, and many other economic sections, to electrical operation.

The use of electricity gave rise to other types of industrial accidents. To those who are unskilled and inexperienced in electrical work electricity is a serious source of potential danger. Electric hazards, unlike many mechanical hazards, are not usually obvious: a live conductor does not differ in appearance from a dead conductor, and the lack of grounding of a metal enclosure or casing may pass unnoticed until it is too late when it is touched and found to be dangerously alive. Electric shock can cause death within a few minutes.

Statistics show that although the number of electrical accidents usually constitutes a small proportion (about 1%) only to the total number of accidents in any particular field of activity, the percentage of electrical accidents which prove fatal is often much higher (about 40%) than the percentage of fatalities in accidents taken as a whole. There is ample evidence that most accidents occur on the alternating current (a.c.) electrical systems operating between 127 and 220 V.

The electric safety requirements examined in this chapter refer to electrical installations under 1 000 V.

8.1. PHYSIOLOGICAL AND PATHOLOGICAL EFFECTS OF ELECTRIC CURRENT

The effects of electricity (electric fields and currents) are specific and, unlike ionizing radiations, do not cause disease with distinct symptoms. Experimental research has shown that electrostatic fields produce biological effect not only on lower forms of living organisms but also on certain vital functions and basic systems of the human body. Electric fields may cause induced surface charges to accumulate on the body, which acting on the sensory nerve endings in the skin give rise to reflex modifications. Spark discharges produce adverse effect on the functions of the central nervous and cardiovascular systems and cause fright and involuntary reactions which may lead to accidents during, for example, pole-top work, etc.

Frequently occurring shock currents can cause morphological skin conditions, such as hyperaemia, blood effusion, oedema and necrosis. Spark discharges cause painful "puncture" sensations and may lead to arrhythmia, bradycardia and breath holding.

Workers employed on d.c. equipment operating at very high voltages may be exposed not only to electrostatic fields and electric discharges but also to airborne ions produced by corona effect. Electrostatic fields and airborne ions are environmetal factors acting upon each other. Their action is to be regarded as that of an electric complex comprising ionized air, capacitative charges and electric fields. Many accidents occur because casings of electrical apparatus carry mains voltage as a result of some defect inside the apparatus, in the socket, plug or cable. When a person touches an electrically charged object there may be a serious, even a fatal, accident if the voltage is above a certain level or threshold[1]. The fundamental approach to electrical safety is the adoption wherever possible, of voltages which are below the level at which lethal current can be passed through the body. However the use of a non-lethal supply voltage is not possible for technical and economic reasons. All industrial accidents including electrical accidents are, either directly or indirectly, attributable to human failings. Man is not a machine, his performance is not fully predictable, and he sometimes makes mistakes. The great majority of electrical accidents occur as a result of contact with electrically charged objects using a.c. supply.

The result of an accidental contact with an electrically charged object is the electrical shock, or electroplexy, which leads to all sorts of injuries and sometimes even death.

---

[1] The generally accepted thresholds are: three-phase grounded neutral a.c., 42 volts; single-phase a.c., 24 volts; direct current, 110 volts. The maximum shock voltage to earth is 55 V. The value of safety low voltage recommended by the IEC is 50 V.—*Translator's note.*

Electrical injuries include electrical burns (Joule burns), skin metallization, and mechanical damage.

An electrical burn may be caused by an electrical current passing through the body or by an electric arc. Heavy arcing may cause severe burns as the temperature of an electric arc is usually higher than 3 500°C. The passage of an electric current along any conductor is accompanied by the dissipation of heat. According to Joule's law, the dissipated heat is directly proportional to I^2Rt where I is the current in amperes, R is resistance in ohms and t is the time in seconds. As the skin is the site of highest resistance in the body, it is there that burning is most likely to occur when contact with live conductor is made. Such burns may be deeper than may first appear on clinical examination. Consequently, healing is slow and may be accompanied by much scarring.

Metallization or crusting of the skin is the result of an electrolytic effect of current on the human body which leaves the so-called "signs of current" or crusts on the affected skin surface.

Mechanical damages are the result of muscular contractions caused by the passing current and include ruptures of the skin, blood vessels and nerve tissue, dislocations and even fractures. Referred to this type of injury are also contusion and fractures due to falls from elevated places, strikes against protruding parts of equipment or against structural elements during involuntary movements or loss of consciousness.

Electric ophthalmia, i.e. damage to the eye caused by eye-flash from electric arc (welding), UV and infrared radiations.

By severity, electric shocks can be classed in four groups:

Group I—tetanic muscular contractions;
Group II—tetanic muscular contraction aggravated by loss of consciousness;
Group III—loss of consciousness and arrest of the heart or respiratory function, or both, and
Group IV—clinical death.

Clinical death is a period during which it is still possible by the appropriate means to restore the function of the nervous cells (central nervous system) caused by the disfunction of the respiratory and circulation organs. In higher animals and in man failure of such functions does not lead to the immediate occurrence of irreversible changes in the cellular and tissue structures. Some organs reserve their functions for a long time. The existence of such a period when it is possible in a number of cases to restore vital functions and to reanimate the body has led to the notion "clinical death". The length of the clinical death period varies from 2 to 6, sometimes to 10 minutes and depends on the severity of the injury and individual characters of the victim.

The factors that determine the severity of electric shock are the electric resistance of the body, magnitude, duration, kind and frequency of the current, and the pathway taken by the current through the body.

Most of the body resistance is in the skin, the internal milieu having a fairly constant resistance of about 500 Ω for large and wet skin surfaces, and more than 100 000 Ω for thick calloused skin (Fig. 65). For calculations, the resistance of the human body is assumed to be equal to 1 000 Ω.

The effect produced by an electric shock also depends on the current magnitude, but the great majority of electrical accidents occur on

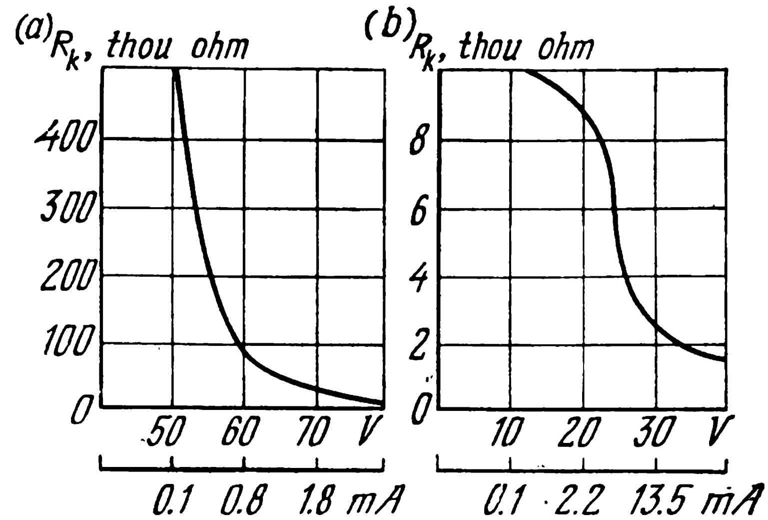

Fig. 65. Resistance of the human body *vs* voltage of a.c., 50 Hz, source (*a*) dry skin; (*b*) wet skin

installations delivering a fixed voltage. Under these circumstances the magnitude of the current depends on the electric resistance of the human body; because the human body acts as a volume conductor, currents of 50 Hz generally travel through it in a uniform manner, there being little evidence to support the view that the current preferentially flows along blood vessels. At these frequencies, the body behaves as a simple resistance with virtually no capacitance or inductive effect.

The threshold of separation for the current passing along a conductor held in the hand is about 1 mA. Such current is called the threshold "let-go" current. It causes no injury but sensation and varies between 0.6 and 1.5 mA. As the current is gradually increased, tingling, heat and pain are felt, and at about 10 mA an average adult is unable to let go because the forearm muscles are held in tetanic contraction. Such current is known as the threshold "let-no-go" or holding-up current. Most accidental electric shock currents pass through the chest and if the current is about 20-40 mA, the chest muscles are held in contraction and respiration ceases to function.

This may cause death from asphyxia within a few minutes with hypoxia and profound mixed acidosis. However, if the current is interrupted within 2-3 minutes, respiration restarts spontaneously and recovery is usually rapid.

Persistent respiratory arrest is caused only by the electrical shock current passing through the centers controlling respiration which lie in the lower posterior part of the brain. Urquhart and Noble in 1929 demonstrated that an a.c. passage through the spinal cord produced a condition of temporary block. It was also found out that transmission of nerve impulses along a segment of an exposed peripheral nerve could be prevented by previous passage of an a.c. along this segment. This phenomenon was called the "a.c. block" and was used to explain those clinical cases in which arrest of respiration persisted after the shock current had stopped. It has since been shown that in the absence of ventricular fibrillation, persistent respiratory arrest occurs only when the current passes through the respiratory centre. Description of accident cases in which current flew between the head and the limbs, resulting in prolonged respiratory arrest led to the teaching that prolonged artificial respiration by itself was the correct treatment of electrical shocks.

Ventricular fibrillation is a state of disordered action of the heart and may result from a shock current passing through the chest. In ventricular fibrillation, regular heart action ceases, the pulse is absent, and circulation is arrested. The heart will fibrillate only if the current passes during the period when the ventricles are just relaxing, a phase which may occupy up to 25% of a single heart cycle. The threshold value of the current to cause fibrillation is above 100 mA, and is called the threshold fibrillation current. This value serves the basis for the current-sensitive earth-leakage circuit breaker designed to operate in the event of an electrical accident so as to rapidly disconnect the supply before the ventricular fibrillation is produced.

The longer the victim is in contact with an electric current the more serious the consequences. It is therefore essential to rapidly disconnect the supply because durable passage of a current between 25 and 50 mA may also cause fibrillation. The maximum permissible values of alternating current depend on the duration of shock. Thus, passage of an alternating current of 1 mA through the human body is safe for an unlimited time; 65 mA can be safe only for 1.0 s, and 500 mA, only for 0.1 s.

The threshold values of d.c. are higher, thus, the let-go current is 6-7 mA; holding-up current values range from 50 to 70 mA. Usually the effect from d.c. is heat, and the electrical burns produced by direct current may be very serious and even fatal when the voltage is high. As a rule, d.c. installation use supply voltages under 250 to 300 V and this makes them less dangerous. The existing standards

for the safe construction and use of electrical installations apply equally to both a.c. and d.c. electrical apparatus.

Because the body behaves as a volume conductor, the current density is greatest along the line joining the two points of contact. It is therefore very important to consider the current pathway and the structures along it, because these determine the effects of the shock. The commonest pathway is between one of the upper limbs and either the opposite upper limb or the lower limb. This pathway includes the heart and the respiratory muscles of the chest. Only about 3% of fatal shock currents pass through the head where the neutral centers controlling respiration are located.

The pathways "arm-to-feet" or "arm-to-arm" are most dangerous. The least dangerous "foot-to-foot" pathway (step-voltage) may, depending on the circumstances, lead to serious injuries too.

The mental and physical condition of the victim is very important for the outcome of an electrical shock. Persons suffering from heart disease, malfunction of internal secretion systems, nervous and physical fatigue, intoxication are more sensitive to electrical shocks and thus more liable to injuries. It is necessary therefore that persons employed to operate electrical installations be not only skilled and trained in electrical work but be at regular intervals medically examined.

8.2. FIRST AID

As was mentioned earlier, the great majority of electrical accidents occur as a result of contact with current-carrying parts of electrical installations. In all cases, nothing but prompt and efficient help only can prevent serious injury and save the life of the victim. It is therefore very important that the personnel be trained and instructed in first-aid measures. The immediate step is to rapidly disconnect the body from the live conductor; any delay may be fatal. To separate the victim holding a live conductor by physical efforts is difficult because the victim's hand muscles are held in tetanic contraction. It is not advisable however to do that without the necessary precaution as his body becomes a conductor itself and touching him with bare hands is dangerous. Prompt disconnection of supply is what should be done in the first place. Measures should be taken to prevent the victim from falling down in cases when the electrical accident occurs at a site elevated from the ground. Supply cutoff may affect lighting in the area of the accident during night hours, so emergency illumination should be timely provided. In cases where disconnection of supply is impracticable, every effort should be made to separate the victim from the current-carrying parts of the installation by force, pulling the body by the items of his clothing making sure first that they are dry and loose over the body. It will be noted that touching

metal parts is dangerous and should be carefully avoided. When pulling the victim by feet avoid touching his shoes which might prove wet and thus dangerous (Fig. 66).

When touching the victim's body is unavoidable, use rubber gloves or any insulating material (dry cloth, wood, etc.) available at hand.

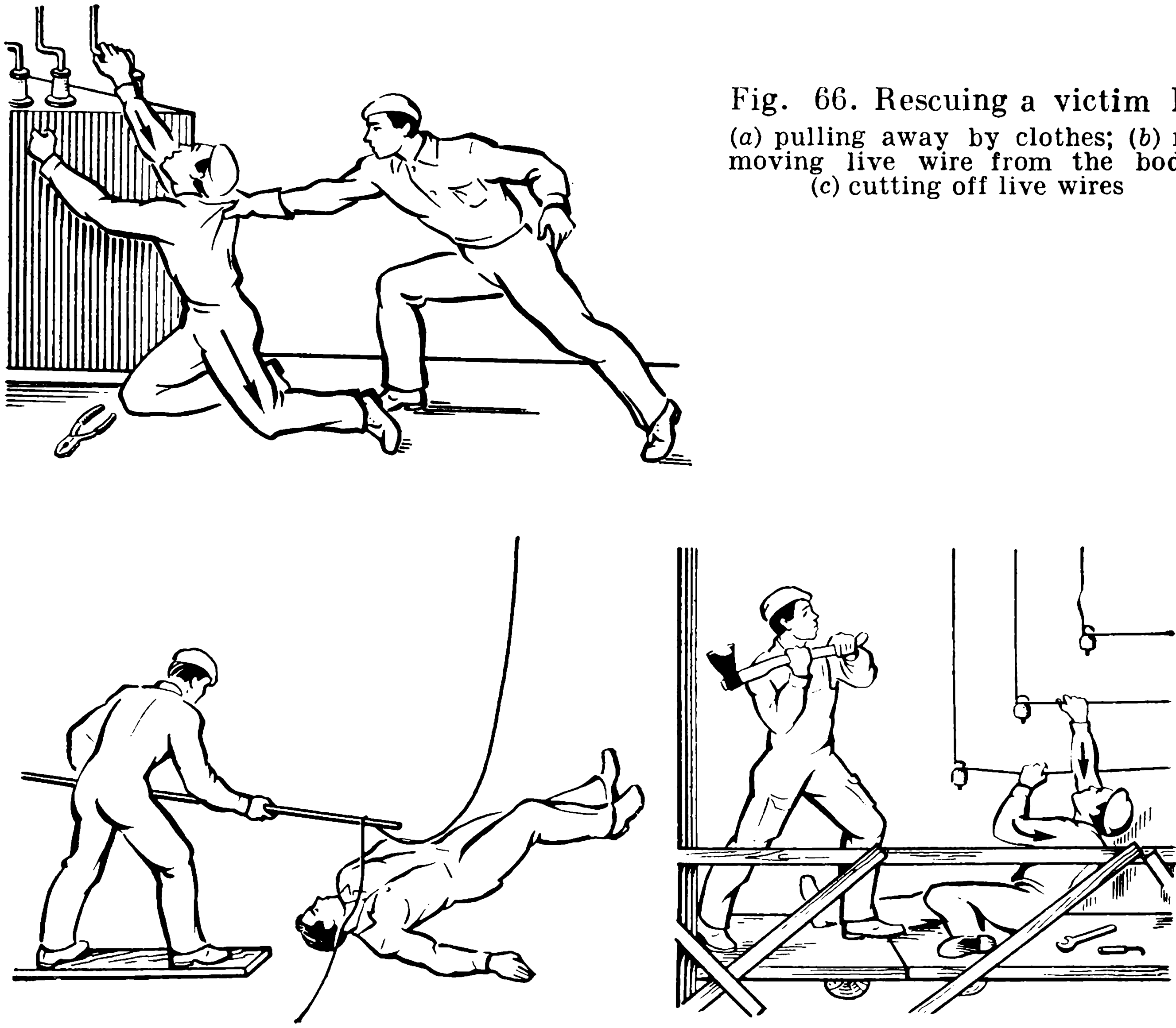

Fig. 66. Rescuing a victim by (*a*) pulling away by clothes; (*b*) removing live wire from the body; (*c*) cutting off live wires

Do not use wet or metal objects for such purposes. One should remember that pulling the victim with one hand is safer than with two hands. Where necessary electric circuits can be broken by cutting the wires with an axe having a wooden handle or with any available tool with insulated handles. Each wire is cut separately to avoid short-circuiting.

If respiration and circulation are not arrested by the electric shock received by the victim, recovery is usually rapid, with complete rest, fresh air and medical assistance timely provided.

First aid measures to be taken in electrical accidents depend on the health condition of the victim. It has been shown that the symptoms of clinical death from electric shock are:

(a) arrest of the circulation from ventricular fibrillation;

(b) asphyxia from sustained contraction of the chest muscles;

(c) persistent arrest of respiration caused by the current.

Arrest of respiration may complicate the arrest of circulation. Therefore in all cases nothing is lost by a prompt and efficient artificial respiration (resucitation) which should be continued until breathing starts again.

Artificial or assisted respiration comprises methods of artificial ventilation of air in the lungs of the victim. Resort to artificial

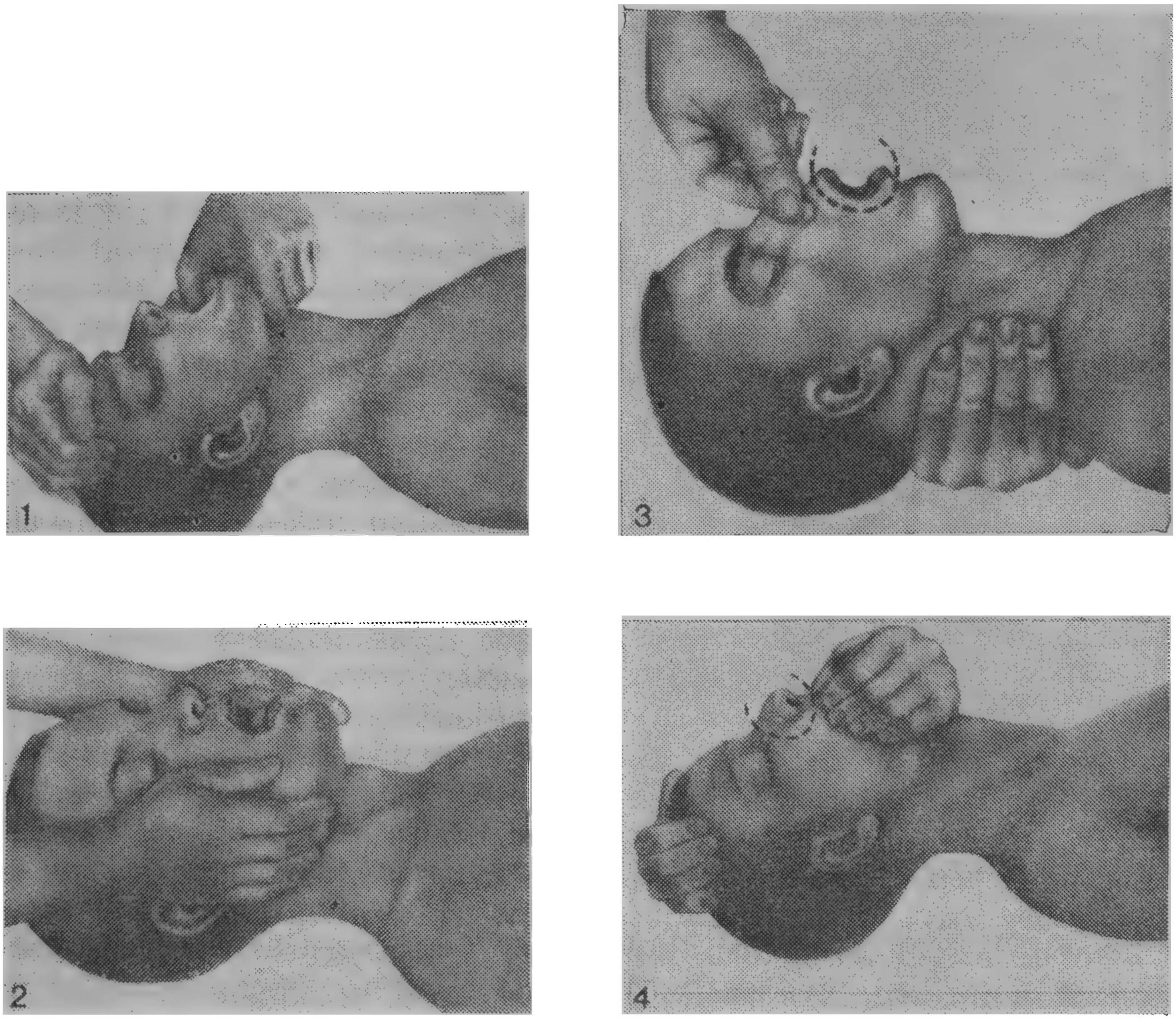

Fig. 67. Artificial respiration techniques
1-3 — mouth-to-mouth; *4* — mouth-to-nose

respiration is often made when natural respiration ceases or disrupts to an extent that it is dangerous to life. It is the first-aid measure necessary to be applied in the case of clinical death, i.e. when respiration and circulation are arrested. The duration of artificial respiration depends on the severity of respiratory disfunction and should be continued until natural respiration function is completely restored. It is to be stopped with clear symptoms of death (livores mortis and rigor mortis).

Prior to starting artificial respiration the victim's nasal and oral cavities should be cleaned from saliva, phlegm and tenacious mucus. His chest, abdomen and limbs must be freed from everything that may restrict movement. The victim should be put on a flat rigid surface, such as ground, floor, bench or wooden board. A roll of cloth, a pillow or a similar item should be tucked under his shoulders.

To perform mouth-to-mouth artificial respiration (Fig. 67), find a suitable position near the victim's head which should be thrown back, with the chin raised and the mouth open. If the jaws are clenched, rest the point fingers against the lower jaw corners with the thumb against the upper jaw and move the lower jaw forward. Then, place one hand on the chin and pull it down to open the mouth. Use one hand to keep the head in the thrown-back position and hold the nose with two fingers of the other hand. Inhale deep and pressing your mouth through a handkerchief to the victim's exhale fast the air into his mouth. Raise your head to inhale again and let the chest of the victim to expire. Repeat the procedure at a frequency of a normal breathing.

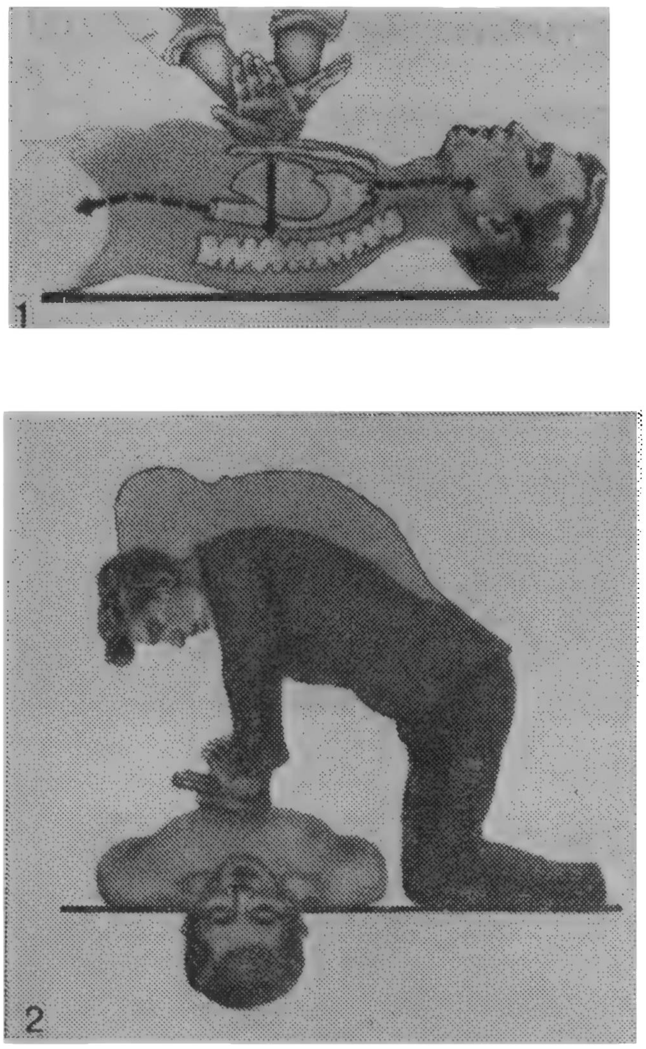

Fig. 68. External cardiac massage

The technique of mouth-to-nose artificial respiration is similar to that described previously. Use one hand to keep the victim's head in a thrown-back position and raise his lower jaw to close his mouth with the other. Inhale deep and covering tight the victim's nose with the lips exhale the air into it through a handkerchief. If the lungs of the victim expire insufficiently during exhalation, open the mouth. It should be noted that the exhaled air contains oxygen in the amount sufficient to support life in the victim.

Both techniques are simple and can be used almost in any situation. The hand methods of artificial breathing (Silvester, Sheffer, Howard, etc.) are less effective, and sometime even dangerous.

Modern first-aid treatment for arrest of circulation is the external (indirect) cardiac massage. By pressing the chest of the victim from the front (Fig. 68), the heart which is between the breastbone and

the backbone, is compressed so that the blood flows from its cavities to the vessels. The pressure withdrawn, it straightens up and the venous blood fills its cavities. So, when performing external cardiac massage, remove your hands each time after the pressure is applied to let the heart straighten up to get blood-filled. To facilitate the inflow of the venous blood to the heart, raise the victim's feet 0.5 m high relative to his head position. It is important to know that this massage does not restart the heart but rather takes over its function in maintaining circulation. For this reason, once started it must be continued until medical aid is available. Defibrillators are used for this purpose in the clinical practice.

8.3. ELECTRICAL ACCIDENTS

An electrical accident may occur when a current of a sufficient magnitude takes the path through the human body. This happens when a person is accidentally brought into an electric circuit or closes a circuit at two points of an electric line carrying a certain voltage. When a person touches a live wire (one phase) a single-phase fault to ground, called partial ground, occurs; if he touches two wires he causes two phases to fault. These electric faults are common for three-phase a.c. networks and systems. Accidents caused by two-phase faults to ground or by a current flow through the body of a person (electric shock) standing on the earth with each foot on a ground point with a different potential (step-voltage) are not infrequent either.

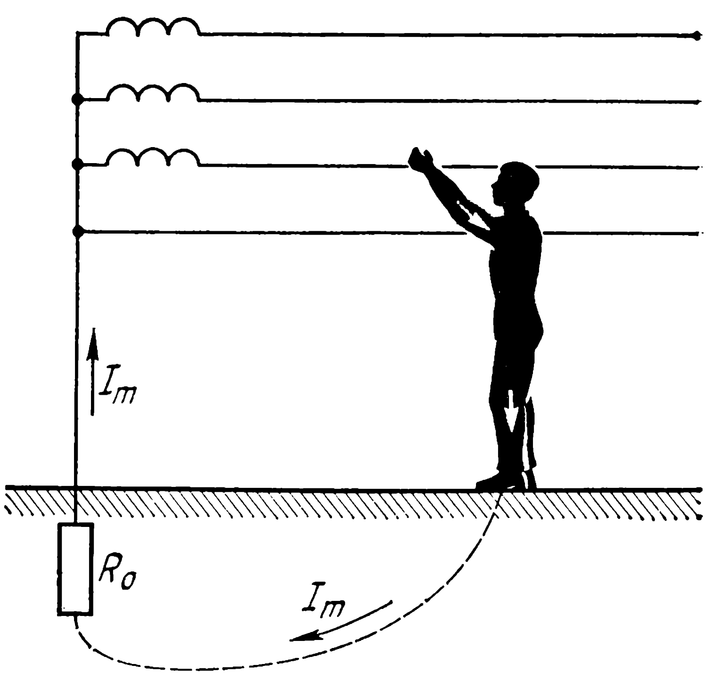

Fig. 69. Ground fault in a three-phase four-wire network with grounded neutral

Single-phase fault to ground or partial earth occurs when a person accidentally touches a casing or part of an electrical installation or machine which normally is dead but becomes alive due to internal fault or defect in the insulation. The severity of the electric shock received by the person in this case will depend on whether the neutral conductor (wire), or the neutral for short, of the network is grounded, or insulated. It will also depend on the condition of the wire insulation, length of the network, mode of operation (load) and on other electric parameters.

When the neutral conductor is grounded, the person is at a phase voltage which is 1.73 times less than the line voltage. The magnitude of the current in this case is determined by the phase voltage of the installation and the electric resistance of the human body (Fig. 69). Also important in this case is the insulating powers of the floor and of the victim's footwear.

So, in three-phase four-wire network with the neutral grounded, the a.c. circuit completed through the body includes resistance of the body, of the floor and the shoewear, and of the grounded neutral of the power source (transformer, etc.). The magnitude of the current in this case is

$$I=\frac{U_l}{1.73\,(R_b+R_{fl}+R_{sh}+R_0)}$$

where U_l is the line voltage, V; R_b is the resistance of the body, ohm; R_{fl} is the resistance of the floor, ohm; R_{sh} is the resistance of the victim's shoewear, ohm; and R_0 is the resistance of the neutral wire, ohm.

To calculate the magnitude of the fault current which takes the path through the human body we shall consider now two cases of a single-phase fault to ground in a three-phase four-wire electric network with the grounded neutral and $U_l = 380$ V.

In the first case, the person who is accidentally brought into circuit is assumed to be standing on a wet ground or a current-conducting (metal) floor, his shoes are wet or incorporate metal nails. From such assumption we take his body resistance to be $R_b = 1\,000$ ohm; $R_{fl} = 0$, $R_{sh} = 0$. We ignore the resistance of the neutral, $R_0 = 4$ ohm being a small value. The magnitude of the fault current

$$I=\frac{U_l}{1.73R_b}=\frac{380}{1.73\times1\,000}=0.22\ \mathrm{A}=220\ \mathrm{mA}$$

is dangerous to the life of the person.

In the second case we assume that the person is on a wooden, dry floor with $R_{fl} = 60\,000$ ohm, and that he wears dry insulating shoes (of rubber) with $R_{sh} = 50\,000$ ohm. Then, the magnitude of the fault current

$$I=\frac{U_l}{1.73\,(R_b+R_{fl}+R_{sh})}=\frac{380}{1.73\,(1\,000+60\,000+50\,000)}=0.002\ \mathrm{A}=2\ \mathrm{mA}$$

is safe even for a long duration.

It will be noted that usually the resistance of dry floors and shoewear is much greater than we have assumed for our calculation.

The above examples indicate the importance of the insulating properties of the floor and shoewear materials in ensuring safety for the worker.

With such a fault occurring in a three-phase three-wire network with an insulated neutral, the current flowing through the human body returns to the source through the wire insulation whose resistance is large (Fig. 70). In this case the magnitude of the fault current is

$$I=\frac{1.73U_l}{3(R_b+R_{fl}+R_{sh})+R_{ins}}$$

where R_{ins} is the resistance of the single-phase (wire) insulation relative to the earth, ohm.

We shall also consider two cases for such networks. In the first case we presume that the floor and the person's shoewear are conduct-

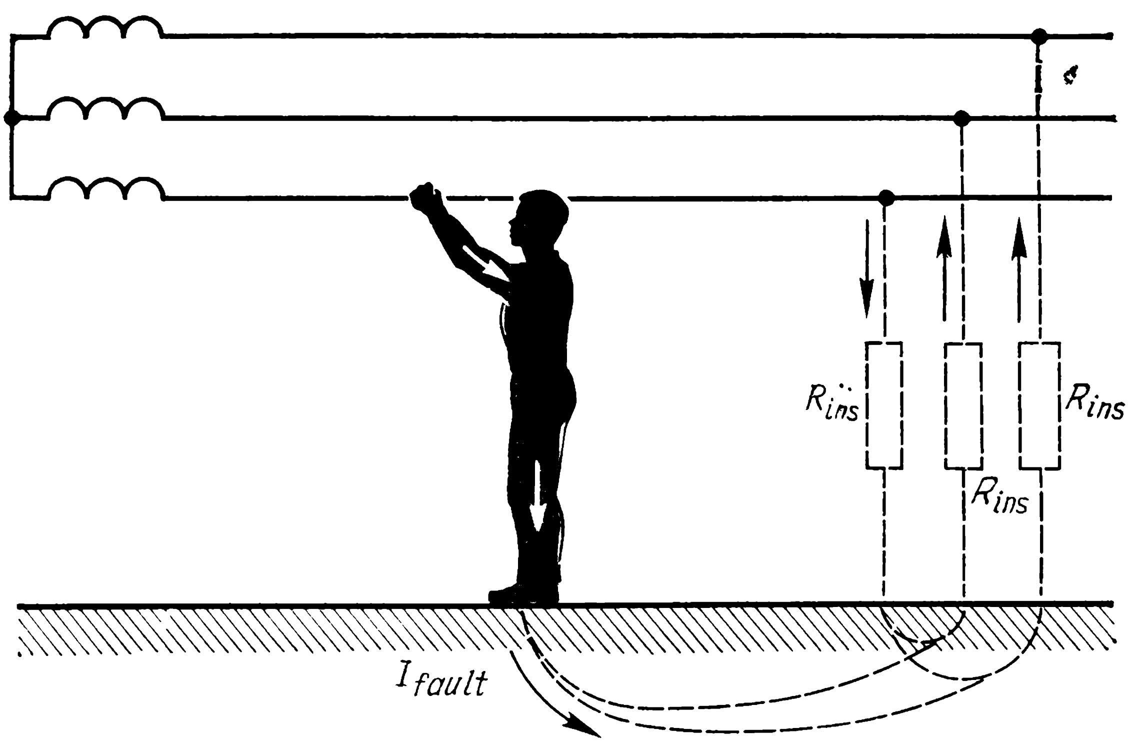

Fig. 70. Ground fault in a three-phase three-wire network with insulated neutral

ing, and hence $R_{fl}=0$ and $R_{sh}=0$. The resistance of the insulation $R_{ins}=60\,000$ ohm. Calculations show that in the network with an insulated neutral the magnitude of the fault current (that takes path through the human body) is 11 times less than that in the network where the neutral wire is grounded.

In the second case, the fault current is safer due to the wire insulation. The larger the resistance of the insulation, the smaller the magnitude of the fault current.

Two-phase fault. When a person touches two different wires or phases of an electric network at a certain voltage, these two phases are faulted. In this case the person finds himself at the full line voltage, and the magnitude of the fault current passing through his body will depend on the line voltage U_l and the body resistance R_b (Fig. 71).

With a two-phase fault, the wire insulation renders no protection

$$I_{fault} = \frac{U_l}{R_b} = \frac{380}{1\,000} = 0.38\ \text{A} = 380\ \text{mA}$$

This current is dangerous and the electric shock may be fatal.

From the above examples it becomes clear that electrical accidents due to ground faults in electric networks with the insulated neutral

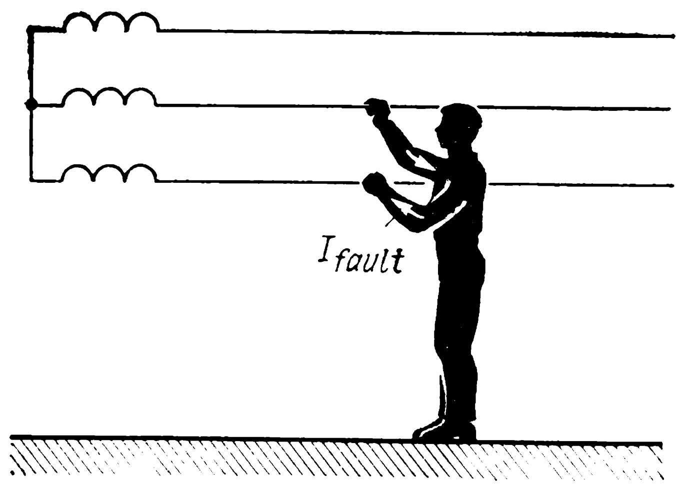

Fig. 71. Two-phase fault

conductor are less dangerous to life than those from faults occurring on electric installations which are not grounded. It will be noted that in the case when one phase is faulted to ground, any accidental contact with the other phase brings the person under the line voltage. This is in fact a two-phase fault, and is dangerous.

8.4. ELECTRIC DANGER CLASSIFICATION OF WORKPLACES

Electricity hazards depend on the environmental conditions. The protective properties of the insulation used in electric equipment and installations tend to deteriorate and the capacity of insulation to resist the passage of electric current decreases in a moist and heated environment and particularly so if the last is aggravated with corrosive gases, vapors, and current-conducting dust deposited on equipment surfaces. As a result the danger of ground fault increases. The risks of electrical accidents are higher where the floors include conducting materials, and the equipment grounding conductors and other metal objects are positioned close to the electrical installations. An accidental contact with such objects may result in a severe electric shock from a large fault current. All this makes it necessary to divide workplaces according to the electric hazards inherent in the place of work.

The Code of practice for the safe design of electrical installations divides all workplaces by the electric danger inherent in them into the following three classes:

Class I: workplaces with dry air, normal temperature and non-conducting floors;

Class II: wet rooms with relative air humidity (long-term average) higher than 75%; hot rooms with air temperature (long-term average) in excess of +30°C; with current-conducting floors and process dust depositions on wires, inner surfaces of electric installations; rooms housing electric equipment with metal casings grounded or connected to the metallic building elements or part of technological installations for this purpose and thus likely to become live, and hence dangerous to the human life;

Class III: very wet rooms with relative air humidity close to 100%, chemically active atmosphere and a simultaneous presence of two or more factors pertinent to workplaces under Class II.

One measure to improve electric safety in workplaces under Classes II and III is to use (extra) low voltage. The examples of the subdivision of workplaces according to the electric danger they present are as follows. To Class I workplaces referred are office rooms and laboratories using precision instruments, assembly shops in precision-instrument manufacturing plants, watch-making factories, etc.; to Class II the classification refers unheated warehouses, storage rooms, stair cases with current-conducting floors, etc.; to Class III—all manufacturing workshops and departments producing storage and primary-cell batteries, etc. Under this last class are also operations and processes performed in the open or in shed.

8.5. ELECTRIC SAFETY STANDARDS AND REGULATIONS

The Code of practice for the safe design of electrical installations is the major standard regulation on electrical safety in industry. The general provisions of this standard (under the heading Collective Protection Measures) envisage that electric safety is ensured and improved by guarding devices, automatic control and protective signalling, protective grounding and earthing of the neutral wire; also by equalizing of potentials and lowering of the operating voltage, use of automatic circuit-breakers, remote control, insulators and insulating materials, fuses, lightning protectors and discharge arrestors, and signs of danger.

The provisions include electric safety precautions aimed at preventing or minimizing the effect on man of electric current, high temperatures, dangerous materials used in processes, and harmful elements emanated during the operation or process.

According to the method of protection used, the standard distinguishes between five classes of electrical apparatus:

Class 0: electrical apparatus that have at least an operating insulation but no design element for connecting it to the ground unless the apparatus refers to Classes II and III;

Class 01: apparatus that have an operating insulation, a design element for its grounding, and a power cable without an extra (earth) wire for the grounding;

Class I: apparatus with an operating insulation and a design element for the grounding. If the Class I apparatus has a power cable, the last should contain an earth wire and a third pin in the plug which is connected to earth through the socket;

Class II: apparatus having a double or improved insulation and no design element for the grounding;

Class III: apparatus which use electric circuits working at 42 a.c. or less, and transformers that reduce the mains voltage to the requisite level. Every transformer used for safety purposes should have the primary and the secondary winding electrically serrated so that in the event of defect the two cannot come into contact.

8.6. SOME PRACTICAL APPLICATIONS OF ELECTRICAL ACCIDENT PREVENTION PRINCIPLES

Causes of electrical accidents are many and diverse. Some accidents are due to technological, mechanical and physical causes, others due to unsafe behavior of the worker. However, of all the causes of accidents occurring during work with electrical installations of up to 1 000 V, the following are often primary:

(1) contact with live conductor;

(2) contact with parts of equipment that accidentally become live due to defect or damage in the installation, or for other external reason;

(3) erroneous application of voltage to de-energized apparatus during repairs;

(4) ground fault and occurrence of step voltage.

One essential measure to prevent accidents of such kinds is the use of guards (metal mesh screens) which allow good visibility but prevent access, use of low voltage, provision of protective earth and protective earthed neutral, cutoff boxes (fuses) and personal protective equipment.

Accidents can be avoided and safety of the worker assured by a suitable overhead arrangement of buses and other supply and distribution systems, protective covering or screening.

Naked conductors, trolley-wires and other electric supply and distribution network inside the buildings should be made possibly overhead at a height of 3.5 m above the floor level. Overhead trans-

mission lines should provide a clearance of not less than 6 m to the ground. Built-in guards and the insulation of the current-carrying parts of certain types of electrical equipment are obligatory. Electric leads, busbars, instruments and apparatus are normally enclosed in specialized sheaths, cabinets, boxes and various other types of continuous or screened enclosures. Insulation of wires prevents electrical current taking undesirable paths and affords protection in the case of accidental contact with electrically charged objects.

Another system that prevents serious accidents is the use of hand tools and apparatus operating on a threshold voltage (42 V a.c.), or less than 36 V in workplaces under Class II, and 12 V in rooms under Class III. Working voltages are decreased to 12 V for work where contact with grounded surfaces is almost unavoidable or work area is hardly accessible (within metal tanks, inspection trenches, etc.).

Low voltages must be used in workrooms with increased and high risks of accidents for the purpose of illumination and for general lighting of the work area where the luminaires are hung not less than 2.5 m above the floor level. Currents of low voltages are used in electrical welding machines; high-frequency (200-2 000 Hz) currents, in electric motor-driven hand tools.

Another important measure to prevent accidents is the protective grounding or earthing.

Protective grounding is intentional connection of the metal parts (casings) of electric or technological equipment to the ground or to some conducting body that serves instead of earth to reduce the potential between the equipment casing and the earth to a safe magnitude. It is a simple, effective method of protection of the workers against high voltage in the case of a partial earth. The method is extensively used in three-phase three-wire a.c. systems up to 1 000 V with insulated neutral, and at voltages higher than 1 000 V with any condition of the neutral.

The protective grounding connection consists of a grounding electrode metal object buried in the ground, grounding conductor, and the earth that surrounds the electrode (Fig. 72).

Protective grounding is based on a sharp reduction of the potential of the current-conducting part of equipment when the current flows in earth to a magnitude

$$\varphi_{gr} = I_{gr} R_{gr}$$

where I_{gr} is the current flowing into the ground, A; R_{gr} is the ground resistance to the flow of current, ohm; and φ_{gr} is the potential of the ground electrode, V.

Along with the positive factor, i.e. reduction of potential of the live part of equipment, the flow of current in the ground builds up a potential in the grounding rod (electrode) and the earth surround-

ing it. This is dangerous as the current tends to spread over an area of a radius of 20 m, called the "leakage spread field". The potential at any point of the field can be calculated. The earth potential around a hemispherical grounding electrode changes according to the law of hyperbola. By applying the equation of the potential

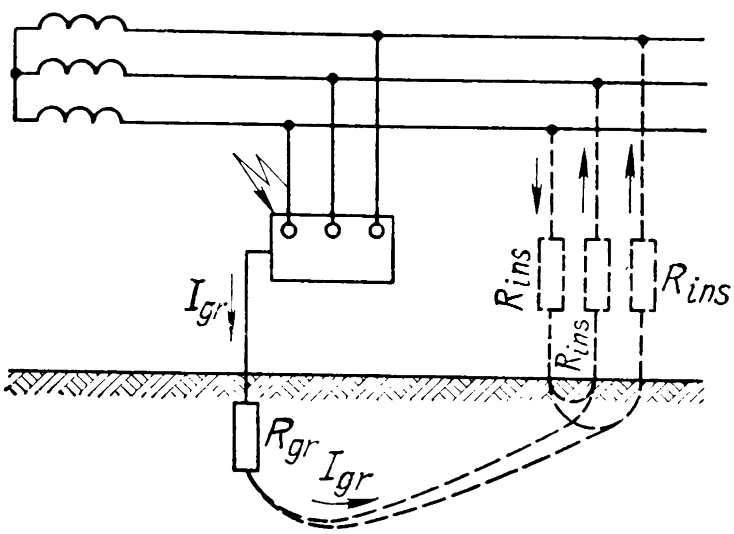

Fig. 72. A schematic of protective grounding

curve for a grounding rod we find that the maximum potential on the rod at a distance from the ground surface equalling to one half of the rod diameter is

$$\varphi_{gr}=\frac{I_{gr}\rho}{2\pi l}\ln\frac{4l}{d}$$

where I_{gr} is the current passing through the ground rod, A; ρ is the resistivity of the earth, ohm; l is the length of ground rod, m; d is the rod diameter, m.

From this, the resistance to the spread of current from a single pipe- or rod-type grounding electrode will be

$$R=\frac{\rho}{2\pi l}\ln\frac{4l}{d}$$

The ground can be established using specialized grounding devices or their equivalents, such as:

(a) water-supply and other purpose metal pipes, except for gas and flammable liquid pipes;

(b) structural metal elements of buildings connected to the earth;

(c) pipe casings, metal cutoff devices of hydraulic structures;

(d) lead sheaths of buried cables.

Such grounding devices must have connection to the grounding system by at least two grounding conductors connected to different points of the grounding device. The provision of an additional, special, grounding device is unnecessary and can be avoided if the available grounding connection ensures the required impedance.

Specialized grounding electrodes can be:

(a) vertically driven into the ground steel pipes 2-3 m long and 25-62 mm across, steel rods 10-12 mm in diameter, and 60 × 60 mm steel angles, etc.;

(b) horizontally laid steel strips, or round wires.

The resistance of the grounds for electrical installation up to 1 000 V should not exceed 4 ohms; for the power sources less than 100 kW the resistance of the grounds can be 10 ohms.

In electrical systems a distinction is made between the operating grounds (for example the neutral of a transformer), and the protective grounds (grounding of machines and apparatus housings) and the lightning protection grounds.

In protection grounding installations it is imperative to keep to the lowest possible values the voltages to which the operating personnel could be exposed if a short-circuit occurs. This is achieved by lowering the resistance of the grounding electrodes and equalizing the potential distribution in the area of the grounded equipment.

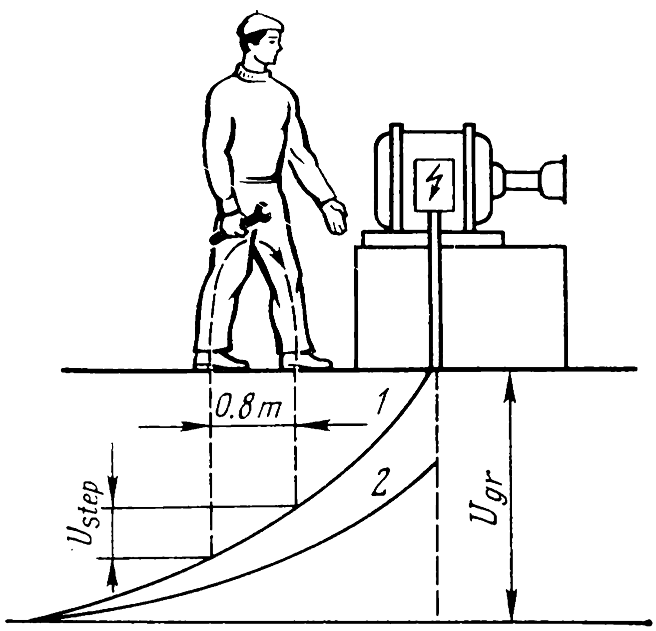

Fig. 73. Step voltage magnitude during ground fault in the apparatus
1 —distribution of potential relative to earth; 2 — step voltage

Safety of the personnel can be ensured if the voltage, called the contact voltage, to which a person may be exposed when touching the grounded equipment which has faulted or when standing on the earth without physical contact with the equipment, the step voltage, does not exceed permissible limit values.

Contact voltage is equal to the difference between the ground fault voltage at the casing and the voltage on the ground surface:

$$U_c = I_{fault} R_b \text{ or } U_c = \varphi_h - \varphi_f$$

where I_{fault} is the current passing through the body by the path "hand-foot", A; R_b is the resistance of the body, ohm; U_c is the contact voltage, V.

Step voltage builds up around the earth point where the fault current flows in the ground, and is equal to the difference of potential of two points on the ground separated by a distance of 0.8 m (step distance) (Fig. 73).

$$U_{step} = \varphi_1 - \varphi_2$$

where U_{step} is the step voltage, V; φ_1 is the potential of the ground under one foot, and φ_2 is the potential of the ground under the other foot.

The magnitude of the step voltage depends on the type of and distance to the electrode. The highest value will be near the grounding electrode, the smallest at a distance of more than 20 m, i.e. beyond the bounds of the current spread field. The resistance of the grounding electrodes can be calculated or measured. The simple rough calculation (to within 5-10%) can be made by the following formulas.

The resistance of a vertically driven pipe or rod

$$R_{pipe} = \frac{\rho}{2\pi l_{pipe}} \left(\ln \frac{2l_{pipe}}{d} + 0.5 \ln \frac{4h + l_{pipe}}{4h - l_{pipe}} \right)$$

where ρ is the specific resistance (resistivity) of the earth, ohm cm; l_{pipe} is the length of pipe, cm; d is the outer diameter of pipe, cm; h is the depth of the center of the pipe to the ground surface, cm.

The formula is valid under the assumption that l is much greater than d and that the uppermost end of pipe is buried at not less than 0.5 m in the ground.

Approximate values of specific resistance of different soil types are given in Table 23.

Table 23

Soil type	Resistivity, 10^2 ohm m	
	at 10-12% by mass of soil moisture	variation range
Sand	7	4-7
Loamy sand	3	1.5-4
Sand loam	1	0.4-1.5
Clay	0.4	0.08-0.7
Blacksoil (chernozem)	2	0.09-5.3

The resistivity of soils depends on the soil texture, moisture and salts content. Variation in the soil moisture particularly in the topsoil causes the specific resistance of the soil to vary within a wide range during the year.

The necessary number of ground electrodes

$$n = \frac{R_{pipe}\eta_s}{R_{gr}\eta_{gr}}$$

where R_{pipe} is the resistance of a single electrode, ohm; η_s is the seasonal factor; R_{gr} is the required resistance of the grounds (operating or protective), ohm; η_{gr} is the screening factor, in other words,

the coefficient of the grounding electrode system (group electrode) characterizing the reduction of conduction in electrodes due to their interplay.

The resistance of a metal strip used to connect pipe electrodes

$$R_{strip} = \frac{\rho}{2\pi l} \ln \frac{2l^2_{strip}}{bh} \text{ (at } l/h \geqslant 5)$$

where ρ is the resistivity of the earth, ohm cm; l_{strip} is the length of strip, cm; b is the width of strip, cm; and h is the depth of the strip burial, cm.

The importance of establishing the ground for human safety can be illustrated by an example.

In the case of a ground fault in a non-grounded electrical apparatus, a contact ($R_{fl} = 0$; $R_{sh} = 0$) with such apparatus would mean a single-phase fault to ground. The magnitude of the fault current passing in this case through the body, with the insulation resistance $R_{ins} = 5\,000$ ohms and the line voltage $U_l = 380$ V, is

$$I_{fault} = \frac{1.73U_l}{3(R_b + R_{fl} + R_{sh}) + R_{ins}} = \frac{1.73 \times 380}{3 \times 1\,000 + 5\,000} = 0.082 \text{ A} = 82 \text{ mA}$$

Such current is dangerous and the accident can be fatal.

Under similar conditions but with a ground established, $R_{gr} = 4$ ohms, the fault current taking path through the victim's body will be

$$I_{fault} = \frac{1.73 \times 380}{3R_b + R_{ins} + (R_b R_{ins})/R_{gr}} = \frac{657.4}{3 \times 1\,000 + 5.000 + \frac{1\,000 \times 5\,000}{4}}$$
$$= \frac{657.4}{1\,258\,000} = 0.000\,5 \text{ A} = 0.5 \text{ mA}$$

This current magnitude is practically safe, and is not conducive to injury.

Specialized grounding systems used to connect apparatus, machines and other electric installations to the earth consist of metal electrodes buried in the earth (ground electrodes) and the conductors connecting these electrodes to the grounded parts of the apparatus. Ground electrodes may be in the form of pipes, metal rods and steel angles driven vertically into the ground to ensure good contact with the earth. The electrodes are usually 2.5-3 m long buried so that their upper end is at the ground level, or driven a little deeper into the earth. The grounding electrodes (pipes, strips, etc.) must be installed so as to equalize the potential distribution in the area of the grounded equipment. In contour grounds the electrodes are placed along the perimeter of the protected structure at a distance of 1-2 m from the structure.

The ground must be established for all electrical installations rated for 500 V and higher a.c. and d.c.; electrical apparatus rated for 36 V

a.c., and those rated for 110 V d.c. and installed in workplaces under Class II and III and outside the working enclosures, i.e. in the open; all electrical apparatus using a.c. and d.c. irregard of voltage and installed in workplaces where the risks of exposion can be expected.

The use of the grounds instead of a phase or neutral conductor is prohibited.

The connection of the grounding conductors to installations to be grounded must be effected by welding and to the casings of machines and apparatus by welding or bolting. The grounding conductors must be protected against corrosion. For this purpose lengths of bare

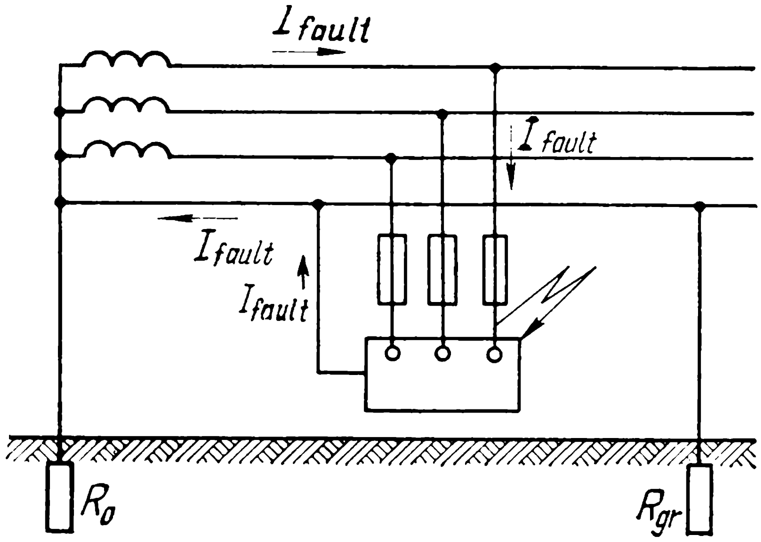

Fig. 74. Grounded neutral system

conductors and systems of conductors which are not buried are usually given a coat of black paint; paints of other colors can also be used for this purpose depending on the interior finishing colors. In this case the points of connection or branchings are marked with two horizontal black lines spaced at 150 mm.

The locations of the grounding conductors inside rooms should have access for their regular inspection.

Neutral grounding or *grounded neutral system* is a means to ensure a safe operation of electric installations (Fig. 74). In this system the neutral is connected to the ground either solidly at several points or through a resistance or reactance of a low value. The grounded neutral system is used in a three-phase four-wire electric networks up to 1 000 V. Casings of machines, apparatus, parts of installations are connected to the grounded neutral to be protected against ground faults. Protection is ensured through automatic disconnection of power supply to the installation which has faulted. In this system the ground fault can be regarded as a short-circuit between a phase wire and the neutral wire. The fault current actuates the current protection system (circuit breaker) which rapidly disconnects the apparatus from the mains. In this case it is important that the fault current will be larger than the operating current of the fuse or of

the automatic circuit-breaker tripping device

$$I_{fault} \geqslant kI_{rated}$$

where I_{rated} is the current magnitude at which the fuse blows or at which the automatic circuit-breaker is set to operate, A; k is the safety factor which is equal to 1.4 for circuit-breakers up to 100 A; 1.25 for other circuit breakers; 3 for fuses or automatic circuit-breakers with reverse-current tripping devices; 4 for fuse protection; and 6 for automatic circuit-breakers in explosion-prone installations.

To ground the neutral, use is made of steel strips, metal sheaths of cables, tracks of travelling cranes, metal structural elements of

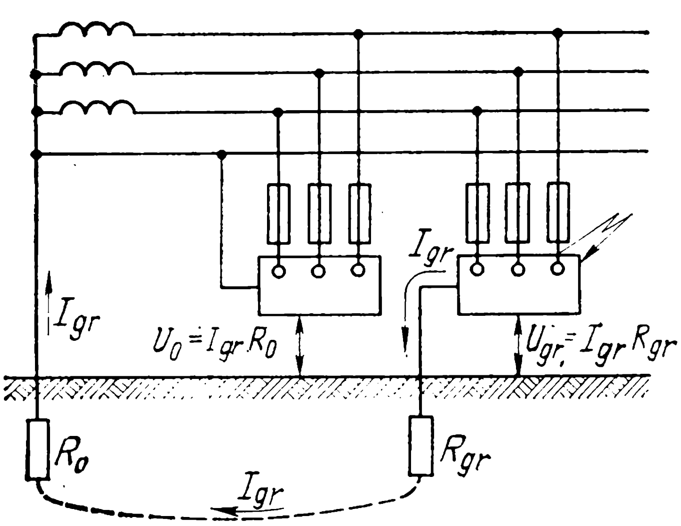

Fig. 75. A schematic to show inadmission of a simultaneous establishment of protective grounds and a grounded neutral system in one electric network

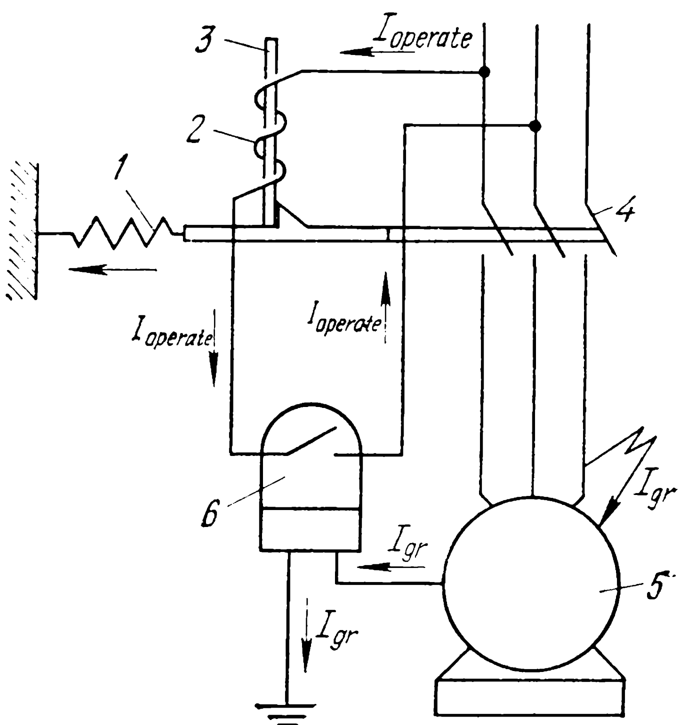

Fig. 76. A schematic of protective tripping

1 — spring; *2* — electromagnet winding; *3* — core; *4* — switch; *5* — electric motor; *6* — intermediate relay

buildings, etc. Connected to the grounded neutral usually are all metal parts of electric equipment which are otherwise directly grounded. The use of the grounded neutral system and protective grounding in the same electric network is inadmissible for reasons of short-circuiting should an internal fault in the grounded equipment occur (Fig. 75).

Automatic disconnection of supply is an effective means of protecting electrical installations against the effects of short-circuiting. For this purpose use is made of automatic circuit-breakers of various types. Such protection is essential when electric safety cannot be ensured by the grounding or where the grounding is impracticable.

Automatic circuit breakers provide a rapid (within not more than

0.2 s) disconnection of power supply to the electric equipment, machine or installation in the event of ground fault due to a defect in the insulation or other reason, sudden increase of the operating voltage, accidental touching by a person of electrically charged objects or parts of equipment.

The advantages of automatic protection by tripping the current are in that it can be provided for all electrical installations regardless of the voltages for which they are rated and of the conditions of the neutral and in that tripping occurs within 0.1-0.2 second by relatively low voltages of the fault current of about 20 to 40 V.

The disconnection is effected automatically by circuit-breakers equipped with special tripping devices. There exist many types of such circuit-breakers and switches. Fig. 76 shows schematically the principle of the operation of a circuit-breaker tripping device. The circuit breaker consists of an electromagnetic coil, a core which in its normal position holds the contact closed. One lead of the coil is connected to the casing of the electric installation being protected, the other to the grounding electrode. As the voltage on the casing builds up to 24-40 V, the core moves within the coil due to an electric current induced in it thereby actuating the spring of the switch contact which gets open thereby disconnecting the power supply to the installation.

8.7. BASIC SAFETY REQUIREMENTS FOR ELECTRIC INSTALLATIONS

The requirements apply to the insulation of wiring, safety devices, motors and switches.

Insulation plays an important part in electric installations as it prevents excess leakage of current, protects people from electric shocks and eliminates fire hazards.

The Code of practice for the design of electrical installations establishes that the resistance of insulation at a section of network between two safety devices or behind the last fuse installed between any wires should be not less than 0.5 Mohm.

In wet workplaces or where releases of corrosive vapors and gases are common the insulation strength should be 20 to 50% higher depending on the operating voltage.

The insulation resistance of an electric installation should be measured after erection, repair, and periodically during the operation not less than once a year in Class II workplaces and not less than twice a year in Class III workplaces. This precaution is necessary because the dielectric properties of the materials used for the insulating purposes with time tend for some reason or other to deteriorate.

Wiring in industrial premises usually includes insulated wires or cables which where necessary are tubed to avoid mechanical damage. Non-insulated wires or buses can be used only as contact (trolley) conductors for power supply to electric cranes. Such contact wires should be arranged overhead at a height of not less than 3.5 m above

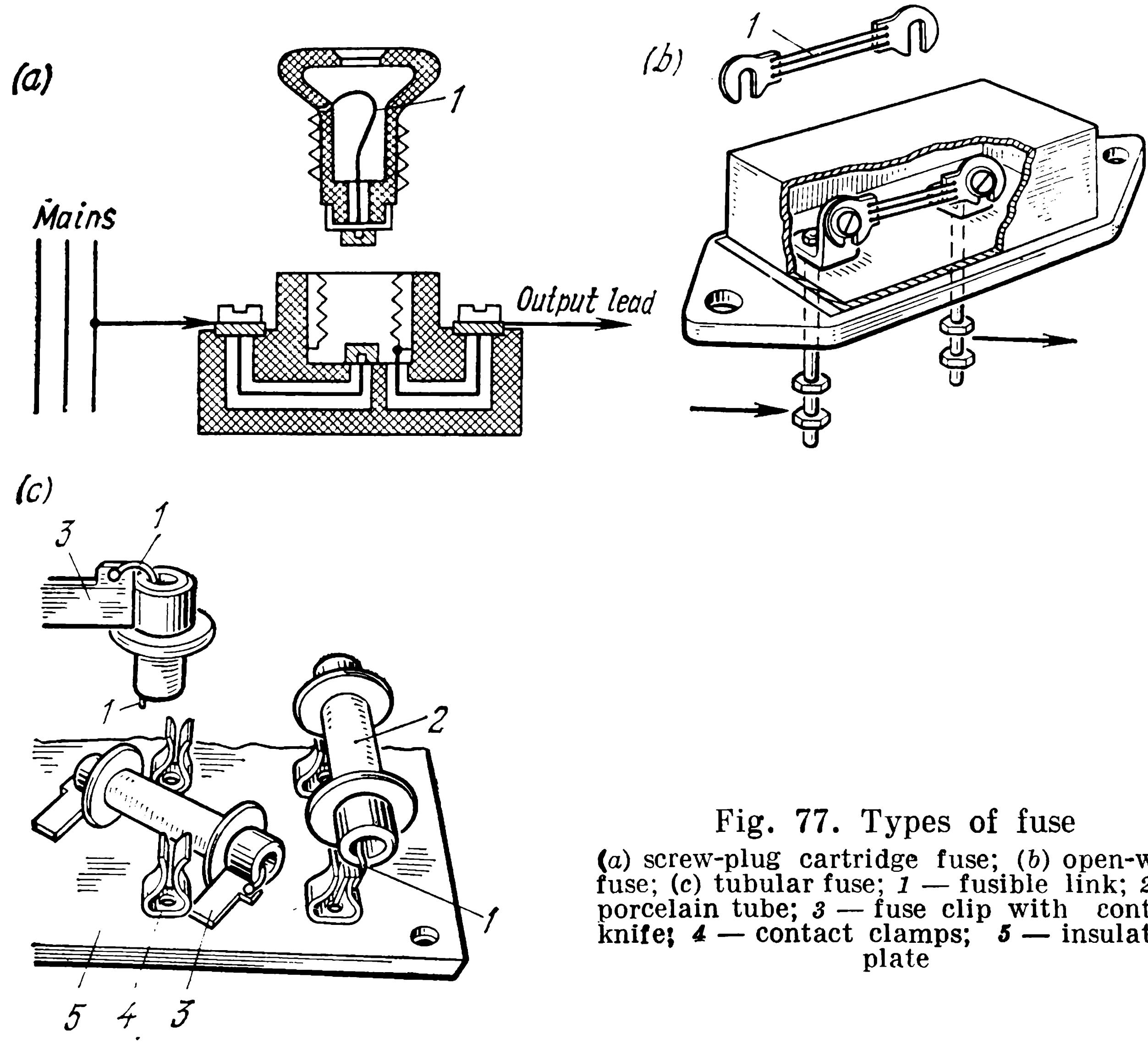

Fig. 77. Types of fuse

(*a*) screw-plug cartridge fuse; (*b*) open-wire fuse; (c) tubular fuse; *1* — fusible link; *2* — porcelain tube; *3* — fuse clip with contact knife; *4* — contact clamps; *5* — insulating plate

the floor level. The overhead naked trolley systems are equipped with automatic switches of instant action which disconnect the supply in the event of breakage of a wire.

Safety devices known as fuses are simple electric protective appliances intended to disconnect an electric apparatus, machine or installation from the supply line when the value of the current in the circuit exceed the rated value. The fuse is designed to blow (burn) as soon as the current passing through it exceeds 25% of the value for which the apparatus is rated. The time of blowing of the fuse link depends on the magnitude of the current. When the passing current is 2.5 times that of the rated, the fuse blows immediately, with no delay. The use of copper wires instead of standard fuses is prohibited for reasons of safety and prevention of fires.

Fuses used in electrical installations can be of several types: screw-plug cartridge fuses, open-wire fuses, and tubular fuses (Fig. 77),

each type comprising all the parts that form a unit capable of performing the prescribed function.

Screw-plug cartridge fuses are used to protect lighting installations and electric motors of a low capacity, and are called low-voltage fuses. With the fuse in place, the electric circuit is completed through the fuse link (fusible part that is heated and severed by the passage of overcurrent through it). The inner part of the cartridge incorporating the link is filled with an arc-extinguishing medium, usually asbestos.

The open-wire fuse has a link consisting of one or several wires of a fusible metal and mounted on an insulating base (holder). Such fuses are inserted at distribution cabinets rated for voltages below 220 V.

The tubular fuse consists of a porcelain hollow tube with metal rings on its both end sides connected with a fusible link passed inside the tube. Such fuses are put at distribution points and are enclosed in a box which is normally kept locked.

A switch is usually installed before a distribution cabinet or box regardless of the fuse type to cut off the supply and provide safety for the operator replacing blown fuses or making the necessary adjustments. Replacements of fuses under tension can be performed using personal protective equipment, such as rubber gloves, goggles, mats, and specialized tools, such as fuse hooks or fuse tongs.

Electric motors are used for many purposes and primarily for the driving of machines, tools and equipment in accordance with the technological requirements. Many types of electric motor are available, namely the open-type motor, guarded motor, enclosed-type motor, spark-proof and water-tight motors.

Open-type electric motors are used in Class I workplaces and have their terminal block guarded against accidental contact to eliminate the danger of accidents.

Guarded motors are designed so as to exclude accidental contact with parts under voltage and usually are not water-proof.

Enclosed-type motors are covered with a casing or jacket to protect the inside from dust, chips and other undesirable materials. Normally these motors are air-cooled through metal fins or by a fan placed within the casing.

Spark-proof motors are intended entirely for work in the atmosphere of explosive gases and vapors.

Water-tight motors are designed to operate under water or in extremely wet conditions. These are not necessarily spark-proof and may not necessarily be water-tight.

In all types of electric motors, the terminal block is protected with a built-in guard to prevent accidental contact. All moving parts of electric motors (pulleys, belts, etc.) must be also guarded.

Circuit-breakers are intended to make and break electrical circuits.

The commonest types are the air circuit-breaker and the oil circuit-breaker. The choice depends on the voltage and current magnitudes.

Air circuit-breakers can be knife switches, also blade-switches, and isolators or disconnecting switches. The knife-switch is made enclosed to eliminate accidental contact with current-carrying parts and the risk of electric burns by an electric arc arising when the circuit is opened.

The disconnecting switch of the push-button type is a variety of the knife-switch in which the making and breaking of contact is effected by an electromagnet.

Magnetic (starting) switches or starters have found wide application for switching on and off electrical installations. A magnetic switch is part of an electric controller for accelerating a motor from rest to normal speed, and to stop the motor. It consists of a contact enclosed in a protective casing which is open or closed remotedly from a push-button control panel located near the apparatus or machine which is motor-operated.

Depending on the working environment, choice can be made among the various types of starting switches, namely, open, guarded, enclosed, dust-proof, explosion-proof.

Oil switches are used for electric installations rated above 500 V. The contacts of an oil switch are immersed in oil in which circuit interruption is performed to extinguish the arc. These devices can also be designed to open and close a circuit by non-automatic means or open the circuit automatically on a predetermined overload of current without injury to itself when properly applied within its rating.

Hand tools with an electric drive, such as power drills, nut-drivers, grinding machines, etc., are designed so as to meet the following requirements: allow a rapid connection to and disconnection from the mains, prevent spontaneous connection and disconnection, be safe in use and safeguarded from accidental contact with live parts during work. Many accidents occur because the casings of portable electrical apparatus are carrying mains voltage as a result of some defect inside the apparatus. Accidents have also been caused by defects in the socket, the plug, or flexible cables (Fig. 78).

One essential measure to prevent serious accidents is the use of apparatus rated for low voltages, and of transformers that reduce the mains voltage to the required level. In Class III workplaces safety can be increased by using power hand tools rated under 36 V at 200 Hz, and a power of up to 1 kW.

Where tools operating at low voltages are not available, safety at work in Class I workplaces can be increased by using an insulating transformer rated at 220/110 or 110/110 volts. In Classes II and III workplaces use should be made exclusively of tools rated at not higher than 36 V. If the tool power is insufficient, resort can be made

to power tools rated at up to 220 V. In such cases the essential measure to prevent accidents is the earthing of casings and use of personal protection equipment, such as dielectric gloves, shoes, mats, aprons, etc.

The construction of the electric hand tool or machine should ensure safety in use, and at voltages above 36 V should be providep with a clip to receive a lead not less than 4 mm in diameter to the grounding conductor or to the earthed neutral.

The hand tool is connected to the mains by a single- or multicore cable or a wire enclosed in a flexible rubber tubing with an insulation power rated for a voltage of not less than 500 V.

Electric welding operations can be performed with stationary or portable welding machines using a.c. or d.c. supply and positioned

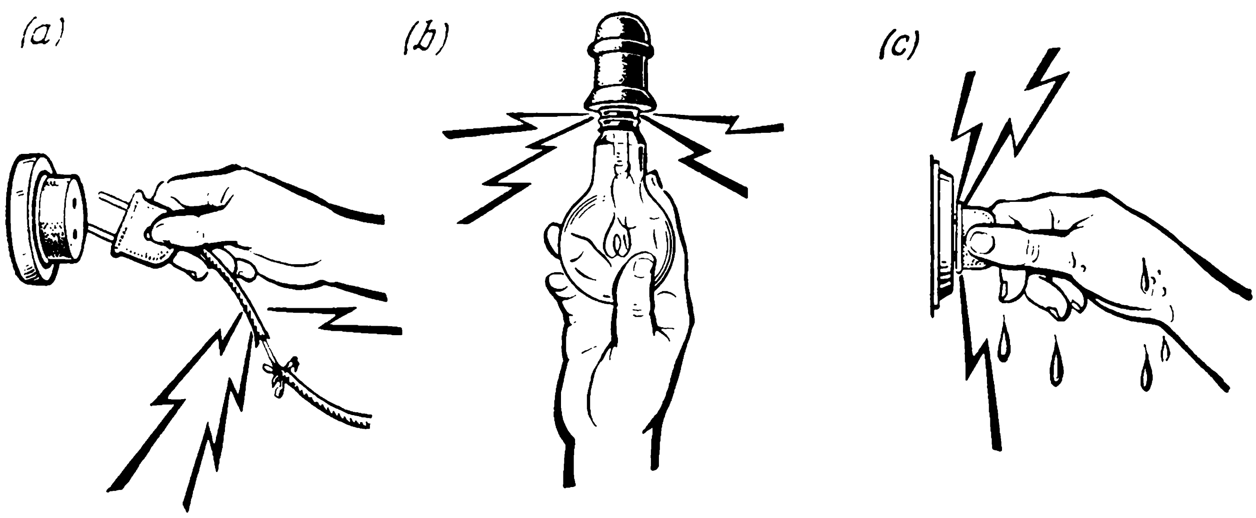

Fig. 78. Electrical accidents due to defect
(a) in cable and plug; (b) in screwed lamp-holder; (c) contact

at welding stations which can provide for automatic or hand welding of all sorts of butt, spot and continuous weld joints.

The power source of a welding apparatus must be located as near as practicable to the welding station. The d.c. power sources are normally grouped and located in a separate room or rooms so that the distance to the welding station does not exceed 40 m.

Welding power generators and transformers as well as conciliatory apparatus and instruments necessary for welding can be installed outdoors, provided they are enclosed or well guarded, have waterproof insulation, and put in shed made from fire-resistant material for the protection from atmospheric precipitation.

All welding machines, apparatus and automatic welding devices must have built-in protection (fuses) against overload on the high-voltage side.

The use of the grounding system or grounded neutral wire, water-supply pipes, metal structures of buildings or process equipment for the return cable during welding operations is prohibited.

The d.c. voltage of welding power sources running idle should not exceed 80 V, and that of transformers, 70 V.

Electric-arc welding operations, both manual and automatic, inside pressure vessels, boilers and other enclosed metal structures can be performed only if the welding machine is equipped with a protective tripping device which breaks the welding circuit with a delay of not more than 0.5 s after the arc is extinguished. Outside watch should be continuously maintained as long as the welding operation inside the vessel proceeds.

Welding operations on closed heavy pressure vessels or vessels containing flammable or explosive materials are prohibited.

8.8. PROTECTIVE EQUIPMENT

Protective means are devices, stationary or portable, intended to protect the personnel operating electrical equipment and installations from electric shock and injuries associated with electrical accidents (Fig. 79).

Protective devices fall into *primary* and *supplementary* insulating means. The former are designed to withstand the operating voltages and permit the operator to touch the conducting parts if necessary without endangering himself, or causing injury to others. Referred to such protective devices and tools used for work with electric apparatus rated above 1 000 V are coupling and measuring hooks (sticks), insulating and measuring tongs, fuse pullers, voltage indicators, insulating devices and appliances for repair work. For the electric installations rated below 1 000 V the primary protective devices are coupling rods and measuring tongs, dielectric gloves and hand tools with insulating handles, and voltage indicators.

Working on electrical installations rated below and above 1 000 V may require that supplementary protective means be also used in addition to the primary protection devices. Such means include the use of dielectric gloves, shoes or boots, mats and insulating pads with insulating supports (Fig. 79*g-i*).

With all electrical apparatus regardless of voltage rating *insulating sticks* or *rods* (Fig. 79*a*) are used for operating disconnectors and isolators which have no mechanical drives, for establishing the grounds during measurements and tests conducted on the equipment to which voltage is normally or accidentally applied.

Insulating tongs (Fig. 79*b*) are used for replacing blown fuses, protective caps, and for similar operations. Sometimes these are known as fuse pullers or fuse tongs.

No other protective devices but *dielectric gloves* and *shoes* or *boots* (Fig. 79*c-e*) which are manufactured specifically to satisfy the requirements of the Code of practice for use and testing of protective equipment applied to electric installations. Such means must be

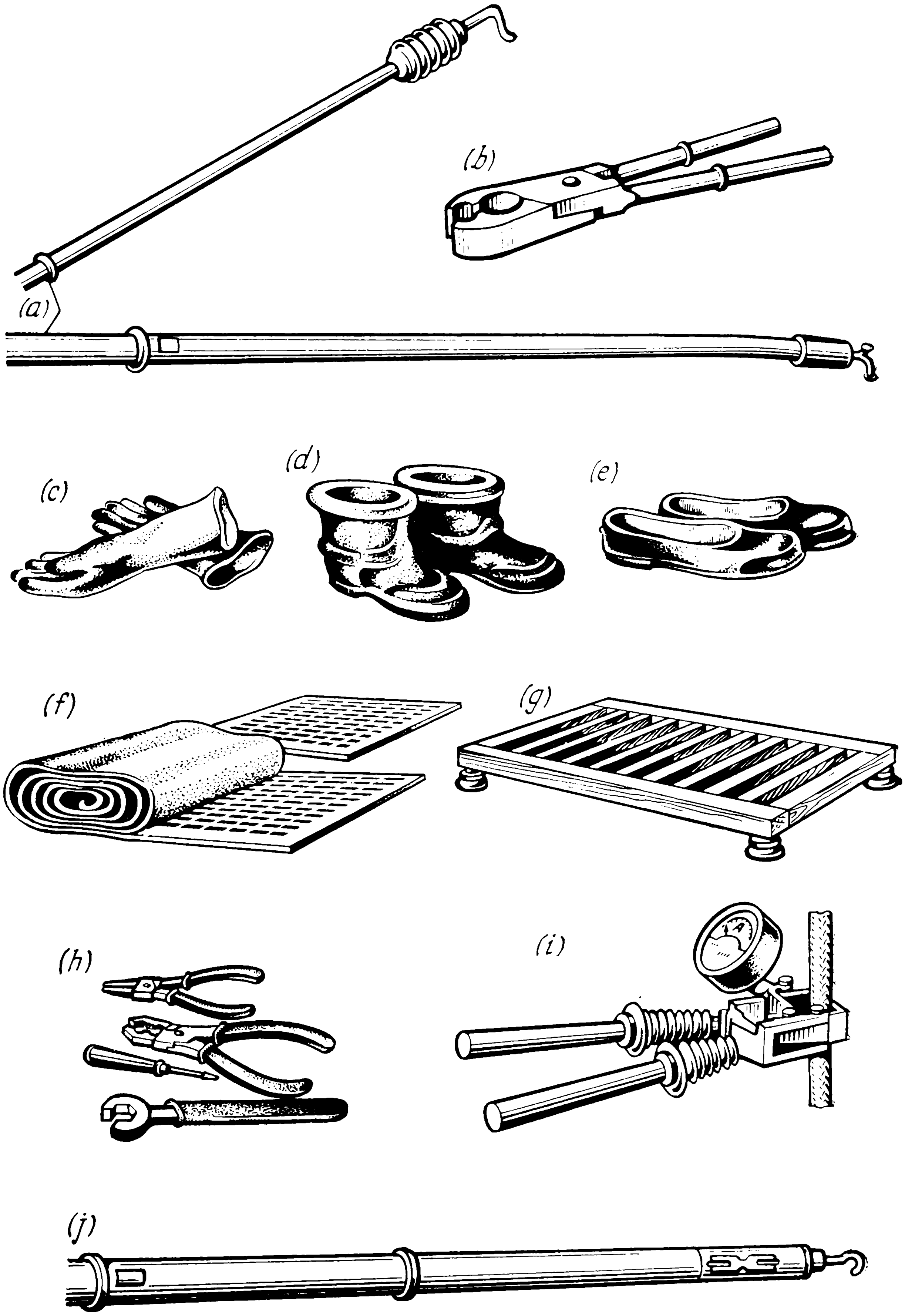

Fig. 79. Protective devices

(a) insulating stick; (b) insulating tongs; (c) gloves; (d) and (e) dielectric shoes and boots (f) rubber mats; (g) insulating support; (h) tools with insulating handles; (i) voltage indicator; (j) measuring tongs

used only for the specific purposes for which they were designed and manufactured.

The use of rubber gloves, shoes and boots intended for purposes other than specified by the Code (everyday wear, etc.) is prohibited.

Insulating stands or *supports* (Fig. 79*g*) consist of a wooden boarding resting on insulating legs which are not less than 10 cm high. Insulating supports should be of sound material, of adequate strength and strain to which they will be subjected, and include no metal fixtures or stiffeners.

Strict observance of safety rules is essential in operating and maintaining electrical installations. Every high-voltage unit should be properly guarded to exclude accidental contact of the operators with high-voltage terminals and leads, measuring devices, resistors and other elements and parts of high-voltage circuits. It is permissible to run a high-voltage unit only in the presence of two operators, one in charge of the job. Before switching on a high-voltage source, all the doors and protective guards should be tightly closed; the unit can be connected to the power supply only with the supervisor's permission. After applying the voltage, any switch-overs in the circuits, replacements and readjustments of the operation are inadmissible. High-voltage units, machines and equipment must have warning notices, such as "Care, high voltage" at the places where they catch the eye, warning lights and a set of insulating means, such as rubber mats, gloves and tools with insulating handles.

CHAPTER 9

Safety of Pressure Systems

Compressed air, gases and steam at a higher than atmospheric pressure find extensive application at engineering plants. Compressed air is utilized in metal-cutting machines, die casting, pneumatic drills, hammers and other tools. Compressed gases are used widely for heating in furnaces, driers, and in gas welding operations. Steam is also used extensively for heating purposes in process equipment, in heating installations, and in ventilation systems for heating the air during the cold period.

Application of compressed air, gas and steam gives the opportunity of improving technology, mechanizing labor-intensive manufacturing processes, automating production and improving working conditions. At the same time, pressure vessels and apparatus are factors of industrial hazards conducive to accidents because they may cause excess heat and gas and danger of explosion.

9.1. PRESSURE VESSELS

A pressure vessel is a hermetically sealed receptacle intended to carry out pressurized chemical or heat processes, store and handle compressed, liquified and dissolved pressurized gases and liquids. The boundaries of the vessel are the inlet and outlet connection points.

Rules of the safe design and operation of pressure vessels are contained in the code of practice which specifies all safety precautions to be taken during the manufacture, erection, maintenance and use of pressure vessels. Vessels for compressed liquified and dissolved gases should conform to the rules of the code and, in particular, be of material of good quality, free from significant defects, and of adequate thickness. Every user must keep a vessel maintenance register or ledger in which noted should be, under the corresponding dates, all tests, internal and external examinations, cleanings and repairs undertaken on the pressure vessel.

Pressure vessels must be inspected and tested by qualified inspectors:

(a) before being placed in service for the first time;

(b) before being placed in service after repairs other that the overhaul maintenance;

(c) periodically at intervals determined by competent authorities with due regard to the nature of medium for which the vessels are used.

It is the duty of the management to ensure that the inspections are made.

All pressure vessels must be so designed, manufactured and installed as to be convenient in use, inspection, cleaning and maintenance.

Any violation of the above code of practice regarding the design and installation or of the operating instruction of pressure vessels is conducive to an explosion that may result in the destruction of equipment, buildings, production structures, injuries to and poisoning of the operating personnel with harmful substances, and to damage by fire, explosive gases, steam and liquids.

The work of explosion (J) with an adiabatic expansion of gas is expressed as

$$A=\frac{p_1V}{m-1}\left[1-\left(\frac{p_2}{p_1}\right)^{(m-1)/m}\right]$$

where p_1 is the initial pressure in vessel, MPa; p_2 is the final pressure, MPa; V is the initial volume of gas, m^3; and $m = C_p/C_v$ is the adiabat index wherein C_p is the specific heat at constant pressure, J/(kg K); and C_v is the specific heat at constant volume, J/(kg K).

The power of explosion (kW) is

$$N=\frac{A}{t}\frac{1}{102}$$

The manufacturer and the user must strictly follow the safety rules established by the code to avoid and prevent the danger of a prema-

Table 24

Type of vessel	Operating pressure, MPa	Manufacturer's test pressure
Vessels other than cast vessels	Below 5	1.5 σ_{20}/σ_t but not less than 0.2 MPa
Vessels other than cast vessels	5 and higher	1.25 σ_{20}/σ_t but not less than P+0.3 MPa
Cast vessels	Regardless of pressure	1.5 σ_{20}/σ_t but not less than 0.3 MPa

Note. σ_{20} is the maximum permissible stress for the material of the vessel or vessel parts at a wall temperature of +20°C, Pa; σ_t is the maximum permissible stress for the material of the vessel or its parts at the designed wall temperature, Pa.

ture failure of pressure vessels or their accidental rupture by explosion.

All new vessels must be subjected to a hydraulic test. The values of the pressures to which vessels are exposed during the hydraulic testing are given in Table 24.

The ratio σ_{20}/σ_t is normally taken for that material (used in the manufacture of different parts of the vessel) for which its value is the smallest.

The duration of a hydraulic test of a vessel should not last longer than indicated below:

Vessels with wall thickness, mm	t, min
up to 50	10
from 50 to 100	20
above 100	30
cast and multi-layered vessels (regardless of wall thickness)	60

A vessel is said to pass the hydraulic test if it shows no:

(a) signs of rupture;

(b) leakage, drip runs or sweating at welded joints and over the basic metal;

(c) visible residual deformations.

To ensure normal operating conditions all pressure vessels must be provided with:

(a) pressure and temperature measuring instruments;

(b) protective devices;

(c) safety valves and stop gate-valves;

(d) level indicators.

The operating pressure gage is normally installed before the safety valve with the dial mounted in the control panel. The gage is mounted next to the control gage on a three-way valve which provides protection against the direct action of the working medium. The dial of the gages is calibrated so as to ensure easy and visible reading within the middle sector of the dial. The diameter of the dial should be not less than 150 mm when installed at 2 to 5 m above the operator's platform so that the operator has no difficulty in taking readings. The gages are usually installed vertically or inclined at 30 deg frontwise. Gages that bear no manufacturer's seal or stamp of certification, those that are not tested in due time or in which the indicator in the "off" does not return to the zero point, those with a broken or non-glassed dials and with other defects that may distort the accuracy of the reading should not be used for pressure vessels.

Pressure vessels whose wall temperature varies in the course of operation must be provided with instruments to measure the temperature of the medium to control the speed and uniformity of heat-

ing along the length of the vessel. In addition, bench marks are essential on such vessels for controlling heat movement.

Safety valves (Fig. 80) are installed to prevent rupture and failure of vessels by a sudden increase of pressure inside the vessel. The number of safety valves, their size and discharge capacity are chosen so as to prevent an overpressure exceeding the working pressure by

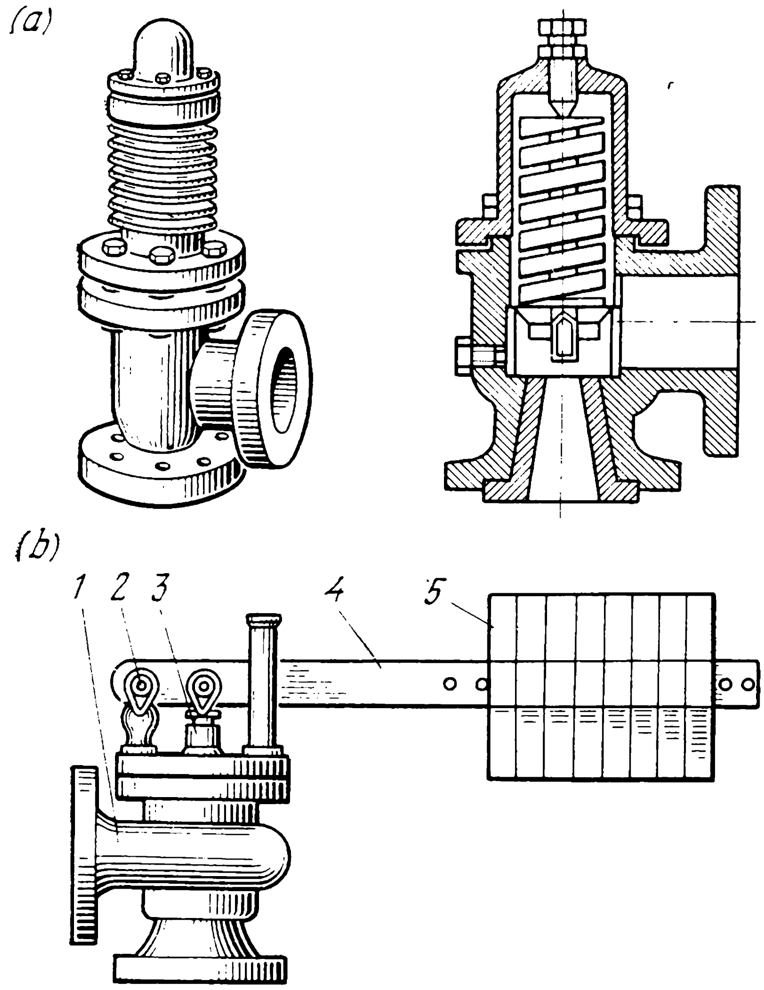

Fig. 80. Safety valves

(a) spring-actuated; (b) lever-operated; 1 — body of valve; 2 — lever hinge support; 3 — valve hinge support; 4 — lever; 5 — counterbalance

0.05 MPa for pressure vessels operating at up to 0.3 MPa, by 15% for vessels operating at 0.3 to 6 MPa, and by 10% for vessels operating at pressures above 6 MPa.

A 25% overpressure is allowed in vessels having safety valves and only in the case when these vessels are designed to withstand such overpressure, which fact is certified by the manufacturer.

The discharge capacity of a safety valve (kg/h) can be calculated using the formula

$$G = 1.59aFB\sqrt{(p_1 - p_2)\rho}$$

where a is the coefficient of the gas flow rate through the valve determined experimentally by the manufacturer for each construction of valve, and is included in the manufacturer's certificate;

F is the valve section area (the least area in the passage section of valve), mm^2; p_1 is the maximum excess pressure before the valve, Pa; p_2 is the excess pressure after the valve, Pa; ρ is the density of the medium at p_1 and t, kg/cm^3; B is the coefficient (from tables) which for fluids equals unity; and t is the valve outside temperature, °C.

Safety valves are usually installed on branch-pipes or feed-pipes directly connected to the vessels at points easily accessible for inspection.

In the cases where safety operation for some reason or other cannot be ensured by a safety valve (if proved by calculations), safety of the operation is achieved by a safety membrane installed before the valve and rated to withstand pressures up to 25% in excess of the working pressure. In such cases a device must be provided to control the physical condition of the safety membrane; the latter must bear the manufacturer's seal and markings as regards the ultimate permissible pressure in conventional writing or specialized symbols. Such particulars may also be marked in paint in a durable and easily visible manner on the vessel side wall.

Stop valves are installed on pipes which supply to and remove steam, gas or fluid from pressure vessels. Installing stop valves or gate-valves between the vessel and a safety valve is inadmissible.

Level indicators (Fig. 81) are mandatory features of pressure vessels which are flame heated or filled with liquified gases, and where the fluid level may drop below the flame line.

The erection and maintenance of pressure vessels and the manufacture of vessel parts must be carried out by specialized teams of workers of the contracting organization, and in accordance with the technology specified by the manufacturer. The materials used must satisfy the strength and plastic characteristics specified in the design, and show good weldability. Welding operations should be performed by skilled and specially trained welders. The quality control of the welded joints in pressure vessels and vessel parts includes:

(a) external examination and measurement;

(b) flaw detection by ultrasonic, X-ray and γ-ray testing methods, or by means of their combination;

(c) mechanical testing;

(d) metallography;

(e) hydraulic testing;

(f) other methods of testing recommended by the technical specifications.

Each user must keep a pressure vessel inspection and maintenance register in which noted are all tests, external and internal examinations, repairs and cleanings undertaken on the vessel. When installed and registered, each pressure vessel should have a 200 × 150 mm plate bearing the vessel registered number, permissible pressure,

date (month and year) of the next internal examination and hydraulic test. These particulars may also be marked in paint in a durable and easily visible manner in a conspicuous place on the side wall of the vessel.

Pressure vessels must undergo technical inspection (internal examination and hydraulic testing) before the vessels are put to opera-

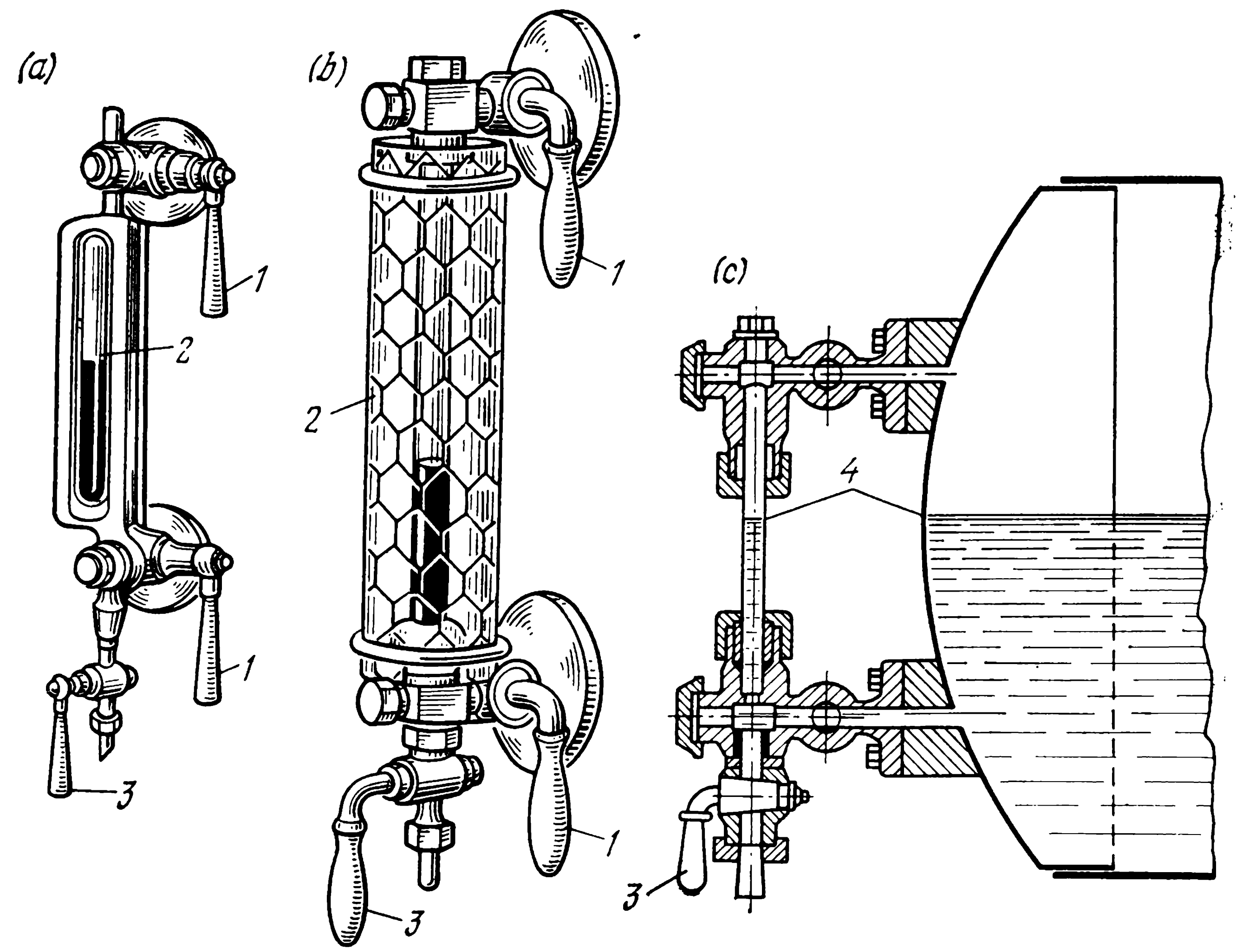

Fig. 81. Water gages for steam boilers

(a) with flat glass; (b) with round reinforced glass; (c) sectional view of a boiler with water gages; 1 — shut-off valve handle; 2 — glass; 3 — discharge valve handle; 4 — water level

tion, and periodically during their service life, by a technical inspector. The internal examination necessary to find out the effect of the medium on the walls of the vessel should be carried out once in 4 years whereas the hydraulic test, once in 8 years after the internal examination. Water, non-corrosive, non-toxic, non-flammable and non-viscous liquids are used for hydraulic testing of pressure vessels.

The user must carry out:

(a) internal examination and hydraulic test of new vessels not entitled to registration with the boiler inspectorate before the vessels are put into action;

(b) once in two years, internal examination of all pressure vessels (registered and not entitled to registration) but once in 12 months

for the vessels operating with a metal-corrosive medium and subject to internal inspection;

(c) periodic external inspection of the operating vessels;

(d) hydraulic test after the internal examination of the pressure vessels not entitled to registration with the boiler inspectorate once in 8 years;

(e) off-schedule technical inspection of the vessels not entitled to registration. The examination must be carried out by a technical inspector responsible for the supervision of all the pressure vessels at a given plant in the presence of the person directly responsible for the safe operation of these vessels. Such technical inspection of the vessels is necessary in the following cases:

(a) after readjustment and maintenance which involved welding or soldering of certain parts in the vessel that are directly exposed to the action of internal pressures;

(b) after the vessel was laid up for more than one year or was put in dead storage for more than three years;

(c) after the vessel was dismantled, moved and erected in a new place;

(d) before applying a protective coating to the walls;

(e) at intervals determined by the supervising inspector or a person responsible for the safe operation of the pressure vessels.

No persons under 18 are allowed to operate pressure vessels. Such installations can be operated by specially trained persons certified and instructed to pass a qualification test for the safe operation of pressure vessels. Each plant should issue a special instruction regarding the operating modes of pressure vessels it employs which should be placed at conspicuous places and distributed among the operating personnel. A competent commission checks the knowledge of the instruction provisions once in 12 months with test results registered in specialized proceeding minutes.

9.2. PRESSURE CYLINDERS

Pressure cylinders are a variety of pressure vessels whose specific purposes require that certain additional safety provisions be met. This section will be devoted to such additional safety standards applied to cylinders.

Strength analysis of cylinders implies that stresses in the walls of the cylinder subjected to a hydraulic test do not exceed 90% of the yield point of the steel they are made of.

The thickness of the wall in the cylindrical portion

$$S = \frac{pD_{in}}{2R_{rup}\varphi} + c$$

where p is the operating pressure, Pa; D_{in} is the inner diameter of cylinder, cm; P_{rup} is the permissible rupture stress, Pa; φ is the safety factor (for seamless cylinders $\varphi = 1$; for welded cylinders $\varphi = 0.7$); c is the factor to account for negative tolerances, cm.

In calculating the strength of cylinders, the safety factor (to yield point) for cylinders from seamless tubes is assumed to be equal to not less than 3; and for welded cylinders, not less than 3.5.

Cylinders of new designs or made from materials that were not used for the manufacture of cylinders earlier are subject to destructive testing by a hydraulic pressure (several cylinders from the first batch). The safety factor should be not less than 2.6 when calculated on the basis of the lower strength limit of metal and the least wall thickness with no allowance for corrosion.

All cylinders, except for dissolved acetylene cylinders should undergo technical inspection, which includes:

(a) external and internal examination;

(b) checking on the weight and cubic capacity, and

(c) hydraulic test.

Cylinders up to 100 liters have no safety valves, nor manufacturer's certificate. On every such cylinder the following particulars are usually marked in a durable and easily visible manner in the upper spherical portion:

(a) manufacturer's mark;

(b) registered number;

(c) weight of empty cylinder;

(d) date (month and year) of manufacture and the year of the next inspection and testing;

(e) operating pressure, Pa;

(f) hydraulic test pressure, Pa;

(g) maximum permissible charge;

(h) seal of the quality control department of the manufacturer.

To prevent the formation of explosive mixtures due to misconnection of the cylinder, provision should be made for locking valves of various sizes and of different direction of the connection screw thread (right- and left-hand). All cylinders for liquified, compressed and dissolved gases must be clearly marked with a text and (or) with different colors for the purpose of identification of their contents in the manner shown in Table 25.

In service, cylinders must be inspected and tested at the plants where they are charged.

Testing of cylinders should be carried out at intervals not exceeding 2 years in the case of cylinders for corrosive gases and 5 years in the case of cylinders for other gases.

The aim of testing is to determine if the cylinder has reduced its weight or increased its cubic capacity. Depending on the test results the cylinders that underwent such changes may be referred to infe-

Table 25

Gas	Color of cylinder	Text	Color of text
Acetylene	White	Acetylene	Red
Air	Black	Compressed air	White
Carbonic acid	Black	Carbonic acid	Yellow
Oxygen	Blue	Oxygen	Black
All other combustible gases	Red	Name of gas	White

rior classes or types. With a loss of more than 20% of weight or an increase of more than 3% of its cubic capacity, the cylinders are rejected.

Before being charged cylinders must have a residual pressure of not less than 0.05 MPa for compressed gases, and not less than 0.05 MPa but not more than 0.1 MPa for dissolved acetylene. Such amounts of residual pressure are necessary to enable the operator to identify the gas or liquid, the given cylinder was filled with earlier, and to avoid the formation of dangerous mixtures. The residual pressure in cylinders for acetylene prevents loss of solvent from the cylinder and eliminates the danger of acetylene explosion.

Cylinders must be provided with reducers to lower the pressure of the gas to the values close to the working pressure, i.e. pressure at which gas enters the burner, cutter or a receptacle with a lower pressure. The reducer lowers the gas pressure at the cylinder outlet and keeps it constant during the entire period of work. It is equipped with two pressure gages, one indicating the pressure in the cylinder and the other, the working pressure at the outlet.

Cylinders for liquified gases must have indicators to show the maximum charge level (90% of their cubic capacity).

The conditions for the storage and handling of cylinders should conform to the following requirements. Charged cylinders should be stored in single-storeyed houses with light and water-tight roofing without attics, of non-combustible materials not below than under Class II of the fire-resistant classification. The doors and windows must open outward. The glass of doors and windows should be frosted or painted white. Natural or artificial ventilation is mandatory. Lighting of the storehouses and rooms must conform to the requirements for the illumination of workrooms that are explosion-prone. Cylinders in storerooms must be adequately protected against excessive variation of temperature, and be placed at a safe distance of not less than 1 m to heating sources and furnaces, and not less than 5 m to open-flame heat sources. All cylinders other than those which are specifically intended to be used, handled and stored horizontally,

should be stored vertically in specialized cubicles, cages, and behind bars that protect them from falling. The cylinders whose base is not constructed for that purpose can be stored horizontally on specialized wooden frames or racks. If cylinders are stored in the open, they must be adequately protected against direct rays of the sun, accumulations of snow, and continuous dampness.

Charged cylinders are handled horizontally with spacers placed between the cylinders. The spacers are normally wooden planks with grooves and slots to receive the cylinders, and (or) rubber or rope rings put in twos around each cylinder (Fig. 82). During the transport, all cylinders are placed with their vents in one direction. Handling of cylinders in a vertical position is sometimes allowed under certain conditions. Properly designed cradle carriages can be used for handling cylinders over the plant area, but not more than two cylinders at one time (one for oxygen, the other for acetylene). *Handling of empty and charged cylinders for oxygen and acetylene together by any kind of handling facility is inadmissible.* Cylinders intended for storage, transport and use of compressed air, liquified and dissolved gases under pressure may explode due to impact, if fallen or dropped when improperly handled or misused, and particularly at elevated or low temperatures.

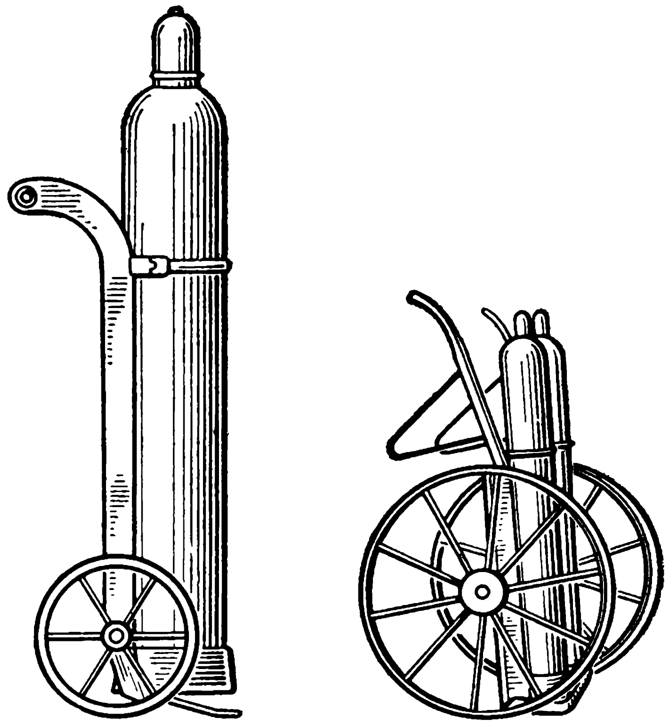

Fig. 82. Cradle-carriages for handling pressure cylinders

Fatty substances, oils and scale at the vent outlet of oxygen cylinders may be the cause of explosion as they are easily ignited when in contact with oxygen, or due to static electricity charge accumulating when the vent is opened too rapidly.

Acetylene cylinders may also explode due to the ignition of the jet of acetylene which leads to a rapid heating of the cylinder and explosive decomposition of acetylene. Heating of acetylene cylinders by external heat sources is dangerous as it leads to excess pressure inside the cylinder, polymerization of acetylene which is accompanied by release of great amounts of heat and results in explosive decomposition. Decomposition of acetylene heats the walls of the cylinder sometimes to red heat. This may cause explosion unless adequate measures are taken to reduce the pressure in the cylinder to a safe level.

Cylinders for liquified gases should not be filled completely: over the liquid level they must have space for gas (or steam), to prevent the generation of dangerous pressures when used at temperatures exceeding the critical temperature.

The limits to which cylinders can be filled are laid down in the manufacturer's instruction, and the proper charging of cylinders is the responsibility of the filling station. A change by 1°C of gas temperature in the cylinder causes a variation of pressure of about 0.05 MPa. Significant increase of pressure and consequent heating of the cylinder may lead to explosion.

9.3. STEAM GENERATORS AND HOT-WATER BOILERS

In this section we shall consider the hazards which may arise when using steam and hot-water boilers, the possible consequences of these hazards, and the measures to prevent accidents of which a boiler explosion is most serious.

Explosion of a boiler is an instant failure of the integrity of the boiler walls accompanied by an instantaneous drop of internal pressure to the atmospheric pressure and immediate vaporization of the water being under pressure and heated to temperatures above 100°C that results in generating an enormous amount of steam (1 liter of water converted to steam increases in volume by about 1 700 times). So, of danger is not the steam occurred in the boiler space, but the water heated above 100°C and possessing high potential energy.

Failures of steam generators may be caused by insufficient amount of feed-water, defects in water feeders and water-level indicators, ignorance or negligence of safety rules, improper work methods or poor discipline at workplaces.

Lack of water in the boiler causes softening of the metal in the firing section of the boiler and bulging of the boiler walls which is conducive to wall rupture.

Scale accumulations in certain parts of the boiler due to irregular cleaning may lead to the bulging of the wall and consequent rupture. Direct contact of water with the boiler walls brought to red heat is extremely dangerous because of the generation of much steam and the formation of zones of high pressure damaging to the walls of the boiler softened by overheating.

Improper water condition is dangerous for the boiler for the following reasons:

(1) the scale forming on the boiler walls has a low coefficient of heat conduction and promotes overheating of the walls and softening of the metal;

(2) soft alkaline water causes a transcrystalline corrosion also known as caustic embrittlement;

(3) air oxygen and carbon dioxide contained in the feed-water

cause an electrochemical corrosion resulting in the formation of ferric oxides on the metal surfaces. Electrochemical corrosion and scale formation can be inhibited by special treatment of the water to remove salts, air, carbon dioxide, and introduction of specialized softening agents into the feed-water.

Rules of the safe construction and use of steam and hot-water boilers are contained in the code of practice, and are applied to all types of steam generators, superheaters and economizers which operate at pressures above 0.07 MPa, and to hot-water boilers intended to heat water to temperatures above 115°C.

Steam generator (*boiler*) is a device consisting of water-drums and tubes which are exposed to the heat of a furnace and arranged so as to promote rapid circulation of the feed-water to generate steam at pressures over the atmospheric pressure for use beyond the generator itself.

Hot-water boiler is a device consisting of a furnace and tubes for heating feed-water under pressures above the atmospheric pressure to be used as a heat-carrier outside the boiler.

There are other types of boilers in which hot gases from manufacturing processes can be used for generating steam or heating water.

In manufacturing plants the calculation of steam boiler is done, in accordance with the established procedure, only for the purpose of checking after the acceptance test and putting the boiler into operation, or for the approval of the boiler for use.

In addition to the instruments which are mandatory for all boilers, water-level (and water temperature) indicators are in a number of cases installed to automatically give warnings by sound or light if the level drops to the minimum.

Insufficient amount of feed-water in the boiler is the most common cause of its damage and explosure. The danger is eliminated by providing a safety plug from fusible (lead-tin) alloys in the upper portion of the furnace. If the feed-water is insufficient the furnace upper portion is not cooled enough and the plug fuses letting the stream into the furnace to extinguish the fire.

Safety valves must be designed so that the over-pressure could not be allowed to exceed 10% of the rated pressure. The total discharge capacity of safety valves should be equal to or exceed the hour efficiency (output) of the boiler.

Hot-water boilers are employed for the heating of production areas and auxiliary premises, and for the purposes required by the production process.

Safety valves for hot-water boilers are calculated using the formula

$$ndh = \frac{Q_g}{pk\,(i - t_f) \times 10^2}$$

where n is the number of safety valves; d is the diameter of valve seat, cm; h is the height of valve travel, cm; k is the empiric coefficient: for low-stroke valves ($n/d \leqslant 1/20$), $k = 135$; for full-stroke valves ($n/d \geqslant 1/4$), $k = 70$; Q is the maximum heating (calorific) efficiency of the boiler, kJ/h; p is the maximum permissible pressure in the boiler with the valve open, MPa; i is the heat content of saturated steam at the maximum permissible pressure in the boiler, kJ/kg; t_f is the feed-water temperature, °C; g is the free fall acceleration, 9.81 m/s^2.

The safety valves of such boilers are set to open at pressures which are not more than 1.08 times the working pressure of the boiler.

Steam generators and hot-water boilers are installed in specialized premises called boiler rooms of boiler houses which must have not less than two exits. Boiler rooms are separated from the production areas by walls made from fire-resistant materials. The roof of the boiler house is made light for easy release and minimum resistance to the blast wave.

The distance from the upper service deck of the boiler to the lower parts of the structure at the ground level should not be less than 3 m. A free passage not less than 1 m wide should be provided between the boilers, and not less than 2 m wide for boilers with side-feed furnaces. Boiler rooms in the basement of buildings can be allowed only if use is made of hot-water boilers operating at temperatures up to 100°C, or steam generators operating at pressures under 0.07 MPa.

Artificial lighting is mandatory. However, for easy and convenient service boiler houses should also have facilities for natural lighting.

9.4. COMPRESSORS

Compression facilities include stationary compressor units and portable compressors of various type and design.

Possible hazards that may arise during the operation of compressors include excessive temperatures and pressures of the gas being compressed; both affect the mechanical strength of the compressor unit and bring about the danger of explosion.

When the air is being compressed without cooling its temperature with consequent pressures rises in the following manner

Absolute pressure, 0.1 MPa	1	2	3	4	5	6	7	8	9	10
Final emperature of air, °C	15	79	123	158	186	212	234	254	277	288

At high temperatures the lubricants used for oiling rubbing parts tend to decompose and vaporize. Oily mists penetrate into the cylinders and form explosive mixtures with the compressed air. At temperatures about 200°C, air mixtures containing about 6 to 10%

oil vapors can explode. The danger of explosion can be eliminated by water cooling of the compressor as a whole or each of its stages. The temperature of the cooling water in the compressor jackets and coolers should not exceed 40°C. The temperature of the air after each stage of compression in the discharge branch-pipes should not be higher than 170°C for general-purpose industrial-type compressors, and 180°C for process compressors. In a number of special cases the temperature should be kept below 160-150°C.

Extremely hazardous are jets of compressed air occasionally released from a compressor due to improper connections or failure of the compressor unit. High velocity streams of compressed air can be very damaging to the personnel of the compressor house and its ancillary equipment.

Compression equipment should be provided with safety valves, signaling and interlocking devices which operate automatically to ensure proper sequence of manufacturing operations and protection of the compression equipment from overload. The number of safety valves, their size are calculated so that the total discharge capacity of valves be equal to, but not less than the efficiency of the compressor unit.

All the moving parts (flywheels, pulleys, shafts and clutches) positioned at a height of less than 2 m above the floor or operating deck level should be protected with continuous or screened safeguards that are made detachable, and easy for removal.

Compressors and pipelines are grounded to eliminate static electricity produced by the friction of dust and scale particles and corrosion products (in pipes) with the metal surfaces, and also by the movement of pulley belts. Dust lodging on oily surfaces produces carbonization the accumulation of which may be the cause of jamming of the pistons, mechanical damage, accidents and explosion.

The air utilized for compression should be cleaned. Cleaning of room air is effected with the help of filters provided in compressors whose efficiency is up to 10 m^3/min. Compressors of high efficiency use outdoor air which is drawn at a height of not less than 3 m above the ground surface.

Compressors are equipped with measuring instruments and protective devices, such as pressure gages, thermometers, automatic pressure governors, safety and release valves, shut-off and gate-valves.

Sometime the pressure may increase locally at certain stages of compression due to defects or malfunction of the admission and discharge valves, and cannot be regulated by the pressure governor. To eliminate the danger of localized over-pressure, safety valves are installed at intermediate stages of compression.

Special-purpose oil with the flash point of about 220-240°C, i.e. higher than the compressed air temperature is used for lubricating

the compressor cylinders. The readings from measuring instruments are taken at intervals of 2 h and are recorded in a compressor operation ledger. Pressure gages are inspected and checked once in 6 months.

9.5. GAS SUPPLY AND OTHER PIPE-LINE SYSTEMS

Low- and high-pressure gasholders are installed at manufacturing plants for storing certain amounts of gas that might be required by the production process.

Low-pressure (1.5-4 kPa) gasholders are used for storage, cleaning of gas from mechanical impurities for uniform distribution of gas, and other purposes. High-pressure gasholders are receptacles intended for the storage and supply of gas at a constant high pressure (up to 1.5 MPa) for the technological needs (to fire furnaces, cut metals, etc.).

Gas is transported by gas-lines also called pipelines which are designed to deliver gas from the gas mains to gas storage facilities and from there to the user. Because of the great diversity of gases used in industry, a system of identification of the contents of pipelines by their color (Table 26) has been devised.

Table 26

Transported medium	Color	Transported medium	Color
Water	Green	Acids	Orange
Steam	Red	Alkalis	Violet
Air	Blue	Flammable and non-flammable liquids	Brown
Flammable and non-flammable gases	Yellow	Other gases	Grey

Rules for the safe design, construction, testing and usage of pipelines are contained in the code of practice for pressure vessels and compressor units, air and gas-lines. According to the code all pipelines should be laid down on consoles or specialized supports to facilitate inspection and testing the connections and couplings for air tightness thereby preventing accidents due to gas leakage, fire and explosion.

Depending on the working pressure, all pipelines for carrying acetylene can be grouped as follows: up to 0.01 MPa, low-pressure pipelines; from 0.01 to 0.15MPa, medium-pressure pipelines; and from 0.15 to 3 MPa, high-pressure pipelines.

Similarly, oxygen pipelines can be also divided into three groups:

up to 0.07 MPa, low-pressure lines, from 0.07 to 1.6 MPa, medium-pressure lines; and above 1.6 MPa, high-pressure pipelines.

Acetylene pipelines in all the three groups, and oxygen-carrying lines for low- and medium-pressures are made from seamless steel tubes. Ground-surface oxygen pipelines can be made only from red copper and tin tubes. The use of lint or hemp fabric for underwinding screw-thread connections, or use of minimum and other materials containing fats for the impregnation or puttying coupled joints in the oxygen pipelines is inadmissible. Use should be made of lead litharge paste puddled with distilled water.

Organic materials, such as pressboard, rubber, rubberized asbestos fabric should not be used as washers in flange and union connections of oxygen pipelines. In such cases, the use depending on the pressure, can be made of asbestos boards or metal washers from aluminium or fired copper.

All flange connections of gas-lines should be grounded and (or) provided with conducting jumpers.

Allowance for a free temperature expansion of pipelines should be made through expansion compensators provided for pipelines to avoid temperature strains and efforts which can be transferred to machines and equipment to which pipelines are connected.

Air-lines and gas-pipes are laid at a gradient of 0.003 in the direction of line water-traps to eliminate zones in which condensate or oil can accumulate. All devices intended for the removal from pipelines of oil and water should be regularly checked. Defreezing of such devices can be done only with hot water, steam or hot air. All the vents, gates and valves should be kept in good shape and order to ensure a reliable stoppage of supply of the air or gas as may be required.

To prevent heat injuries thermal insulation should be installed on all pipelines and apparatus whose surface temperatures are higher than 45°C, and which pass through or are placed near workplaces, and cross the major passageways.

CHAPTER 10

Fire Protection

This chapter deals with the requirements and general principles of fire protection applied to various industrial undertakings of all branches of National economy, including manufacturing industries.

Many factory fires start outside the working hours. In such cases there is no risk of personal accident but the resulting loss of employment and material damage make such fires both an economic and social calamity. Fires occurring during the working hours, however, constitute a very real danger to workers. Much can and must be done to prevent disasters of this kind by those responsible for the building of factories, but the workers should also have a very real responsibility for ensuring the effectiveness of fire-prevention measures.

Fire safety of factories includes preventive and protective measures to be taken to eliminate the causes and sources of fire, and if a fire starts, prevent its disastrous action on the personnel, and ensure protection of buildings, equipment, machines, etc.

Fire safety is ensured with fire-prevention and fire-protection systems which require both organizational and technical efforts to be undertaken by the management and the workers themselves. Various new types of equipment and processes are now employed, developed and planned for subsequent introduction in manufacturing plants. Unless the fire hazardous features of such equipment and processes are understood and explained to the personnel they may present a real danger of fire or explosion. To prevent such disasters it is necessary to inform the workers and other personnel about the risks of fire and explosion inherent in equipment and materials, and about the specific properties of materials and their possible changes during the manufacturing process.

Modern fire protection employs effective systems of rapid fire detection, advanced methods and equipment for fire-fighting which, if used properly and skillfully, permit a fire to be checked and controlled at the very onset.

Russian scientists contributed actively to the development of the theoretical problems of fire control. Thus, the great Russian scientist

M.V. Lomonosov advanced the theory of combustion which has become a scientific basis for the practical solutions to many fire-fighting and fire-protection problems. In 1903, the Russian chemist A.G. Loran offered new method of controlling fires of readily ignitable and combustible liquids by a chemically produced foam; this method has found worldwide application. The works of Academician N.N. Semenov on gas detonation, those of Academician A.A. Skachinskiĭ on the control of gas and dust explosions in mines, and Prof. I.S. Stekolnikov's works on lightning protection have immense scientific and practical significance in the field of fire prevention. Many research establishments today continue research into and development of the problems of fire prevention and fire protection.

10.1. COMBUSTION PROCESSES: GENERAL

Proper organization of fire-fighting and fire protection measures is impossible without a clear understanding of the chemical and physical processes occurring during combustion.

Combustion is a chemical reaction of oxidation accompanied by the generation of large amounts of heat, and by glow. The oxidizing agent in the process of combustion can be oxygen, chlorine, bromine, and several other substances.

In most cases of fire, the oxidation agent is oxygen and this very oxidant will be implied further in our discussion.

For a fire to start, three elements are essential: oxygen (oxidant), fuel (combustible substance) and heat (source of ignition). But it is necessary that the fuel and oxidant are contained in the right proportions and the source of ignition be of such an intensity as to initiate ignition.

The air is known to contain 21% of oxygen. Most substances cannot burn if the air oxygen content is below 14-18%. Only few combustibles (hydrogen, ethylene, acetylene, etc.) can burn when oxygen in the air is less than 10%. With consequent decrease of oxygen in the air, most substances cease to burn.

Combustible substance and oxygen are the reactants that constitute a combustible system in which heat (source of ignition) when introduced can cause the reaction of combustion or burning. The heat source can be any burning or incandescent body, also an electric discharge spark of intensity sufficient to start a fire.

Combustible systems can be homogeneous and inhomogeneous. *Homogeneous* are systems in which fuel and air are in about equal proportions and well mixed with one another (mixtures of combustible gases, vapors with air). The burning of such systems is known as the *kinetic combustion.* The rate of burning is determined by the rate of the chemical reaction which at elevated temperatures is rath-

er high. Under certain circumstances, such combustion may take the form of explosion or detonation.

Inhomogeneous are systems in which the fuel and the air are not mixed but separated with an interface (solid combustibles and non-atomized liquids). To enter into reaction with the combustible material and to continue the burning process in such systems oxygen has to penetrate (diffuse) through the layer of the combustion products to reach the surface of the fuel. Such burning is called the *diffusion combustion*, its rate being largely determined by the rate of diffusion which is rather slow.

To initiate ignition, the heat of the ignition source should be sufficiently intense to turn combustibles into vapor and gas and to heat them to the temperature of autoignition. According to the fuel-oxidant ratio, distinction is made between the poor and rich combustible mixtures. Poor mixtures have more oxidant than fuel. In contrast, rich mixtures have more fuel than oxidant.

The occurrence of combustion is associated with a spontaneous acceleration of the rate of oxidation reaction in the system. The process of spontaneous acceleration of the rate of oxidation turning into combustion is called autoignition. This acceleration, i.e. self-ignition, can be attributed to the three basic processes: heat, chain, and a combination of the two, i.e. heat-chain reaction. The heat theory explains the autoignition by the activation of oxidation and increased chemical reaction due to heat. The chain theory attributes self-ignition to the branching of the chains of chemical reaction. In practice, combustion processes occur by the heat-chain mechanism.

Combustion may be complete and incomplete. The *complete combustion* gives products (carbon dioxide, sulfur dioxide, water vapor) which cannot burn any more. The *incomplete combustion* occurs when the air supplies to the zone of combustion are insufficient or blocked, and gives products, such as carbon monoxide, alcohols, aldehydes, etc., which are still combustible.

Roughly, the amount of air necessary to burn down 1 kg of a combustible substance (or 1 cu m of gas) is

$$V = \frac{1.12Q}{1\,000}$$

where Q is the heat (or calorific value) of combustion, kJ/kg or kJ/m^3.

The heat value of combustion of certain substances is given below

Gasoline (petrol)	47 000 kJ/kg
Wood, air-dried	14 600 kJ/kg
Acetylene	54 400 kJ/m^3
Methane . .	39 400 kJ/m^3
Carbon monoxide	12 600 kJ/m^3

Combustion temperature is determined as a theoretical and actual temperature of combustion.

The theoretical combustion temperature is a temperature to which all the combustion products are heated if we assume that all heat of combustion is used to heat these products. The theoretical temperature of combustion is expressed as

$$t = \frac{Q + mc\theta}{mc}$$

where m is the amount of combustion products formed during burning of 1 kg of fuel; c is the heat capacity of combustion products, kJ/(kg K); θ is the air temperature, K; Q is the heat of combustion, kJ/kg.

The actual combustion temperature is 30-50% less than the theoretical because considerable amount of heat is dissipated into the environment.

High temperature of combustion is conducive to a rapid spread of fire since much heat is used in the preparation of the available combustibles to burning. High temperatures of combustion make fire-fighting difficult.

When considering combustion process one should make distinction between flash, ignition or inflammation, autoignition or spontaneous ignition, and explosion.

Flash is a rapid burning of a combustible mixture without compression of gases.

Ignition is inflammation of a combustible in the presence of a heat source (ignition source).

Autoignition is the result of a sharp increase of the rate of exothermic reactions leading to spontaneous combustion of fuel in the absence of a heat source. Also known as spontaneous or self-ignition.

Explosion is an extremely rapid chemical (explosive) transformation of fuel accompanied by release of energy and compression of gases capable of producing mechanical work.

Combustibility is the capacity of a substance to ignite (inflame) and continue to burn in the presence of a heat source. Also known as inflammability or ignitability.

Spontaneous ignition temperature is the temperature at which a liquid or gaseous fuel will ignite in the presence of air or oxygen.

One should differentiate between the process of ignition (inflammation) and that of autoignition (spontaneous ignition). In order to initiate combustion it is necessary to introduce into a combustible system a heat source with a temperature exceeding the spontaneous ignition temperature. A combustion process started at a temperature below the spontaneous ignition temperature is referred to as autoignition or self-ignition. In this case, combustion is spontaneous, i.e. occurs in the absence of the ignition source: it is caused by self-heating or heating effected by live microorganisms.

Autoignition is possible only if the amount of heat generated during oxidation exceeds that of the heat dissipated into the environment. Spontaneous ignition temperature is a major characteristic of a combustible. It is the lowest temperature at which the rate of exothermic reaction in the combustible, resulting in inflammation, is the highest.

Spontaneous ignition temperatures for some liquids, gases and solids used in manufacturing industries are given below (Table 27).

Table 27

Substance	Spontaneous ignition temperature, °C	Substance	Spontaneous ignition temperature, °C
Phosphorus, white	20	Acetylene	406
Carbon bisulfide	112	Ethyl	421
Celluloid	140-180	Charcoal	450
Hydrogen sulfide	246	Nitrobenzene	482
Petroleum oil	250-400	Hydrogen	530
Kerosene	250	Acetone	612
Gasoline (petrol)	255	Benzene	625
Fuel oil	380-420	Carbon monoxide	644
Fossil coal	400	Coke	700

Apart from spontaneous ignition temperature, all combustibles can be characterized by the period of induction or delay of self-ignition.

Induction period is the time from the onset of self-heating to self-ignition. The induction period for one and the same combustible is different and depends on the composition of mixture, initial temperature and pressure. This period is essential for the action on the combustible of low-intensity ignition sources (spark). A spark generated in a combustible mixture of vapors or gases with air heats up a certain volume of the mixture and then cools. Ignition of the mixture depends on the relation between the induction period and time of spark cooling. If the induction period is longer than the time of spark cooling, the mixture will not ignite.

The fire-hazard classification of gaseous mixtures is based on induction period which depends on the size of dust particles, amount of volatile substances, moisture content, and on many other factors.

Some substances, basically porous solids of organic origin, such as sawdust, peat, fossil coal, etc., can ignite at normal temperature. Self-ignitable also are oils that are spread out with a thin layer over a large area. For this reason oily cleaning cloth is conducive to self-heating in the presence of air or oxygen. When the amount of the generated heat exceeds heat losses by dissipation into the environment, the oily cleaning cloth may self-ignite and start a fire.

The risk of fire from substances liable to spontaneous ignition is high since they can ignite in the absence of external heat at ambient temperatures below the spontaneous ignition temperature. The induction period of self-ignitable substances may last several hours, days, and even months. Acceleration of the oxidation rate can be inhibited only when the dangerous rise of temperature is detected. This indicates that prevention measures in the general scheme of fire protection are extremely important.

Manufacturing plants make use of many substances such as iron sulfides, carbon black, powdered aluminium and zink, etc., which are capable of self-igniting in the presence of air. Self-ignitable become alkaline metals, metal carbides if brought in contact with water. For example, calcium carbide (CaC_2) with water forms acetylene (C_2H_2).

Combustion of gases. Fire and explosion hazards from gases are determined by the concentration limits of ignition (more commonly known as the explosive range), ignition source intensity, combustion temperature and rate of flame spreading.

A gaseous combustible mixture will burn only if it contains the right proportion of fuel. The lowest amount of fuel at which combustion may take place is known as the *lower concentration limit of the explosive range.* The highest concentration of fuel in a combustible mixture at which combustion may still take place is called the *upper concentration limit of the explosive range.* The range of concentrations is called the explosive range (or range of ignition).

The minimum intensity of ignition is the lowest value of the electric discharge spark intensity sufficient to ignite the most readily ignitable mixture of the given gas, vapor or dust with air.

The normal rate of flame spread is the velocity with which the interface (between the burnt and unburnt parts) moves in the mixture relative to the unburnt part of this mixture.

A gas is termed combustible if its mixtures with air are explosive at temperatures below 55°C. Gases such as acetylene, hydrogen, and hydrogen sulfide which have a wide explosive range, low lower limit of the explosive range, low ignition intensity and high normal rate of flame spread are the most dangerous.

Combustion of liquids. All combustible liquids are known to evaporate, so combustion takes place only in the vapor phase over the liquid surface. The amount of vapors formed depends on the components and the temperature of the liquid. Combustion will take place only when the concentration of vapors reaches the explosive range limit.

The lowest liquid temperature at which the proportion of vapors in air is sufficient for the mixture to ignite in the presence of an open-flame heat source without consequent steady-state combustion is known as the *flash temperature* (or *flash point*). No steady-state

combustion takes place at flash temperature because the mixture of vapors and air is not as stable as is necessary for a steady-state burning. The amount of heat released at flashing is insufficient, and the mixture is not yet enough heated to continue combustion.

To ignite a liquid and keep it burning, a continuous not short-lived source of heat is necessary with a temperature higher than the spontaneous ignition temperature of the mixture of this liquid with air.

A liquid is termed combustible if it keeps burning when ignited and after the ignition source has been withdrawn. The flash point of such liquids is not above +61°C (in a closed crucible) or not above +66°C (in an open crucible).

By a *readily inflammable liquid* is meant one which being ignited keeps burning after the ignition source has been withdrawn, and has the flash point below +61°C (in a closed crucible) and below +66°C (in an open crucible).

The flash point is known as temperature at which a liquid becomes extremely dangerous as regards fire. It has therefore been adopted for classifying combustible liquids by their hazard of fire. Fire and explosion risks involved in liquids can be characterized also by the temperature limits of the explosive range of their vapors.

The temperature of a liquid at which the concentration of its saturated vapors in a limited air volume is capable of igniting in the presence of a source of ignition (heat) is known as the *lower temperature limit of the explosive range.* The temperature of the liquid at which the concentration of its saturated vapors in a limited air volume is still capable of igniting in the presence of an ignition source is called the *upper temperature limit of the explosive range.*

The temperature explosive limits of some liquids are given below (Table 28).

Table 28

Liquid	Temperature explosive limits, °C	
	lower	upper
Acetone	−20	+6
Gasoline (petrol)	−36	−7
Benzene	−14	+12
Kerosene	+15	+44
Ethyl	+11	+39

The temperature explosive limits indicate the range of temperatures within which liquid vapors will form combustible mixtures with air.

Combustion of dusts. Certain manufacturing processes involve procedures such as, for example, surface treatment of some solid and fibrous materials, metal-working etc., which produce much dust that in the presence of air may often be combustible. Dust suspended in the air (aerosols) produces combustible mixture, and the dust lodged on the surface of equipment and building elements (aerogels) may smolder and catch fire.

Dust, by fire hazard, is many times more dangerous than the material (product) from which it is formed. This is explained by a greater specific surface of dust particles as compared with that of a solid body. Due to this, dust in the form of aerosoles has lower spontaneous ignition temperature than the solid from which it is formed. Its adsorption capacity is much greater as is the capacity to electrify and self-ignite. The properties of a pulverized material are quite different from those of the same material in a solid state. The oxidation surface is so large that the heat losses into the environment are minimum, and the dust becomes liable to self-ignition (dusts of aluminium, iron, brass, ebony). Autoignition is assisted by adsorption accompanied by heat dissipation.

Like the combustible air-gas and air-vapor mixtures, dusts may explode when their concentrations in the air reach the explosive range. The lower explosive limit of dusts is most important characteristic because dust concentrations corresponding to this limit may be formed both inside the machines treating solid materials, and almost everywhere in production premises.

Dust concentrations corresponding to the upper explosive limit, constituting several grams per cu m of air (13.5 g/m^3 for pulverized sugar) can be formed only inside the machines which grind or mill solid substances.

Dust is said to be the more dangerous, the lower its lower explosive limit and the lower its autoignition temperature.

In contrast to the explosion of air-gas and air-vapor mixtures, the combustion or explosion of air-dust mixtures is characterized by incomplete combustion: burnt are largely the gaseous components while the carbonaceous ones remain unburnt. Therefore, explosive can be only those dusts in which the gaseous components constitute more than 10% of the total mass of dust.

The risks of explosion are high with dusts whose lower concentration explosive limit is below 65 g/m^3 (pulverized sulfur, sugar, flour). Dusts whose lower concentration explosive limit exceeds 65 g/m^3 are referred to explosive dusts.

Manufacturing processes involve many a procedure in which combustion is widely used for various purposes. Combustion is beneficial so far as it is kept under control, beyond which it becomes a disaster known as fire. Standard terminology defines *fire* as the

uncontrollable combustion outside specialized fire-place that causes material losses and destruction.

During fire the combustion temperature reaches 1 000-1 300°C. Such high temperatures are extremely dangerous to the nearby structures, machines, objects and materials as they might readily catch fire themselves.

Knowledge and understanding of combustion processes is essential for eliminating the causes, preventing, checking and fighting the fire, or controlling it from the very onset.

10.2. ACCIDENT PREVENTION DUE TO FIRE IN FACTORY BUILDINGS

Organizationally, there are several important aspects of fire protection which should not be overlooked, namely:

— every undertaking should have trained fire fighters on each shift; large undertakings may have complete fire brigades, and a full-time fire-prevention officer. Fire fighters should be kept in training by regular drills;

— it is essential that undertakings be inspected at suitable intervals for fire risks to see that all fire-fighting equipment is in good condition;

— it is desirable that regular fire drills be organized in such a way as to make sure that all workers know how to use fire-fighting equipment, where the nearest exit is, and how to leave the workplace in good order. From time to time fire drills should be organized to ensure that exits and escape ways are sufficient to enable the factory to be evacuated quickly and that the workers know how to leave the premises in good order. Because sudden stop of production is expensive and it takes some time to resume the work, fire drills should not be abused;

— it is also necessary to ensure close cooperation with the local fire brigade and indicate its telephone number near every telephone. The practice of authorizing only the telephone operator to call the fire brigade is undesirable; it has caused delays in cases of fire that have proved to be extremely costly.

In some factories precautions are necessary not only against fire risks but also against the risk of explosions, which may be very violent and destructive.

Explosions may be caused by substances such as commercial explosives or by concentrations of certain vapors, gases and dusts in the air. The sources of ignition may be open flames, poorly maintained power transmission equipment, unsuitable electrical installations, static electricity, and even smoking.

The probability of occurrence of fire in buildings or structures, and spread of fire is the matter of design, choice of construction

Table 29

Category of manufacture	Characteristic substances involved in manufacture
Fire and explosion hazardous	
A	Combustible gases whose lower explosive limit is 10%, and less by air volume; liquids with vapor flash point up to +28°C (inclusive) capable of producing explosive mixtures with air in volumes exceeding 5% of room space; substances recognized as explosive in the presence of water, air, oxygen, or in mixture with one another
B	Combustible gases whose lower explosive limit is 10%, and more by air volume; liquids with vapor flash point from +28 to +61°C (inclusive); liquids heated during process to flash point; explosive dusts or fibrous materials whose lower concentration explosive limit is 65 g/m^3, and less capable of forming explosive mixtures with air in volume exceeding 5% of room space
Fire hazardous	
C	Liquids with vapor flash point above +61°C; combustible dusts and fibres whose lower concentration explosive limit is above 65 g/m^3, capable of burning only in presence of water, air, oxygen, or in mixture with one another; solid flammable substances and materials
D	Non-flammable substances and materials in hot, incandescent or molten state involving radiant heat, sparks or flame into the environment, solid, liquid and gaseous substances used as fuel
E	Non-flammable substances and materials in cold state
Explosion-hazardous	
F	Combustible gases without liquid phase and explosive dusts in amounts sufficient to produce explosive mixtures in volumes exceeding 5% of room space where, by technology, only explosion can take place (without consequent combustion); substances capable of exploding (without consequent combustion) in presence of water, air, oxygen, or in mixture with one another

materials, size of buildings and their physical position at the industrial site. Access road must be provided to each building and structure, and to sources of water supply (hydrants).

A classification of all production processes has been devised to help assess the risk of occurrence of fire or explosion at factories during certain processes and operations. The fire-hazard classification divides all manufacturing processes, for convenience we shall call

them manufactures, into 6 categories: A, B, C, D, E, and F (Table 29). Using this classification as a guide one can refer the desired process or manufacture to one of these categories, or may consult the code of practice for technological design, or a special list of processes approved and issued by the appropriate competent authority, such as a ministry.

10.3. STRUCTURE AND MATERIAL FEATURES

The first line of fire protection is the construction of the building itself. Industrial buildings must be sufficiently fire-resistant having regard to the fire risks inherent in the processes carried on inside. This is, of course, primarily a matter for architects and designers, but some of the aspects of the problem are matters in which workers themselves can give invaluable assistance.

Fire-resistant construction is to ensure that structural parts do not readily burn and that fire cannot spread through the building either horizontally or vertically through walls, floors, doors, elevator shafts, stair wells, or ventilating ducts.

Building materials and structures differ in their properties to resist fire, stop burning when inflamed and smoldering as soon as the source of heat has been removed. Such properties characterize the ignitability of construction materials and hence the risk of their catching fire, under appropriate circumstances.

Table 30

Group	Inflammability characteristic of	
	materials	structures
Non-flammable	Do not ignite, smolder or char by action of flame or high temperature	Made from non-flammable materials
Hardly inflammable	Ignite, smolder or char by action of flame or high temperature and keep burning only in presence of heat source, but stop burning or smoldering as the source is removed	Made of hardly inflammable materials from inflammable materials but protected with non-flammable coating
Flammable	Ignite, smolder by action of flame or high temperature and keep burning or smoldering after the heat source is removed	Made from inflammable materials

By ignitability all construction materials can be grouped into non-flammable, hardly flammable and inflammable materials. The features by which building materials and structures are referred to different groups are given below in Table 30.

Referred to non-flammable materials and structural elements are metals and inorganic mineral materials such as brick, clay, asbestos, concrete, cementitious binders, gravel, ceramics, sand which are widely used in the building industry.

Construction materials and elements consisting of inflammable and non-flammable components, e.g., straw brick, dry gypsum plaster, fibreboard, ebony and linoleum, refer to the group of hardly flammable materials.

All building materials of organic origin such as timber, cardboard, felt, asphalt, prepared roofing paper, roofing felt and most of the insulating materials are classed as flammable.

Wood in all forms may be referred to the group of inflammable building materials. But given a coating or impregnated with fireproof chemical compounds (fire-retardants such as borax or liquid glass), wood can be classed as hardly flammable.

Fire-resistance classification of buildings and structures. In assessing the capacity of buildings and structures to perform their load-carrying and enclosing functions during fire, knowledge of the fire-resisting properties of building materials and structural elements made from them is essential.

Fire (or flame-) resistance is the capacity of structural elements of buildings to perform their load-bearing and enclosing functions, i.e. retain their strength and ability to withstand action of fire, for a particular time during fires.

It is desirable that the fire-resisting limits of buildings, established experimentally, be sufficiently long to ensure safety and escape of the personnel from the building in fire, or ensure a safe stay in places of collective protection (fire-shelters). The limits are set with no allowance for the effect of fire-fighting on the advance of fire. The limits of fire-resistance are determined by the time (h) from the onset of fire to the appearance of one of the following signs of failure of building:

(a) development of through cracks in the structural elements;

(b) rise of temperature on the non-heated structural surface averagely by 140°C, or in any point of this surface by 180°C as against the pre-test temperature of this surface, or over 220°C irrespective of the pre-test temperature of this surface;

(c) loss of load-carrying capacity (collapse).

The range of fire-resisting limits of single structural elements depends on the size (thickness and cross-section), and the physical properties of the building materials from which the elements are made. For example, 120-mm thick wall can withstand fire for 2.5 h,

Table 31

Class of fire resistance	Major building elements					
	Load-bearing walls, staircase landing walls and columns	Outside walls from panels and external flame work wall	Slabs, floors and other inter-floor and attic floors	Slabs, ceilings, floors	Inner-bearing walls (partitions)	Fire stoppings
I	Non-flam. (2.5)	Non-flam. (0.5)	Non-flam. (1.0)	Non-flam. (0.5)	Non-flam. (0.5)	Non-flam. (2.5)
II	Non-flam. (2.0)	Non-flam. (0.25) Hardly flam. (0.25)	Non-flam. (0.75)	Non-flam. (0.25)	Hardly flam. (0.25)	Non-flam. (2.5)
III	Non-flam. (2.0)	Non-flam. (0.25) Hardly flam. (0.15)	Hardly flam. (0.75)	Flammable	Hardly flam. (0.25)	Non-flam. (2.5)
IV	Hardly flam. (0.5)	Hardly flam. (0.25)	Hardly flam. (0.25)	Flammable	Hardly flam. (0.25)	Non-flam. (2.5)
V	Flammable	Flammable	Flammable	Flammable	Flammable	Non-flam. (0.25)

Note. Shown in parentheses are limits of fire-resistance, h.

those with a thickness of 250 mm are able to withstand fire up to 5.5 h.

The degree of fire-resistance of buildings depends on the inflammability and fire-resisting limits of its major structural elements.

By the resistance to fire, all industrial buildings and structures are divided into 5 classes (Table 31).

10.4. FIRE CHECKS AND STOPPINGS

The fire-resistant construction of a building itself as a measure against fire should include the provision of stoppings, i.e. fire barriers intended to check the fire and limit its spread through the building in any direction. Serving as stoppings can be walls made of fire-resisting materials, fire-check zones, and open space or adequate distance between buildings.

A fire stopping is a fire-check wall of inflammable material with a fire-resistance limit of not less than 2.5 h. It can be made blind or with openings protected by fire-resisting doors or gates. It rests directly on the foundation and intersects all building elements. In

industrial buildings, stoppings are provided to separate the production areas from the management quarters, service and storage rooms, to sectionalize large production floors and storage areas, or to divide an area having various risks of fire, and to minimize the open space between the buildings.

Stoppings can be internal, external, roof- and stand-alone fire-proof walls. The internal stoppings divide the building, the external are normally the outside walls of the building that protect it from catching fire. The internal and external fire-proof walls can be lateral and longitudinal, i.e. built in parallel or normal to the longitudinal

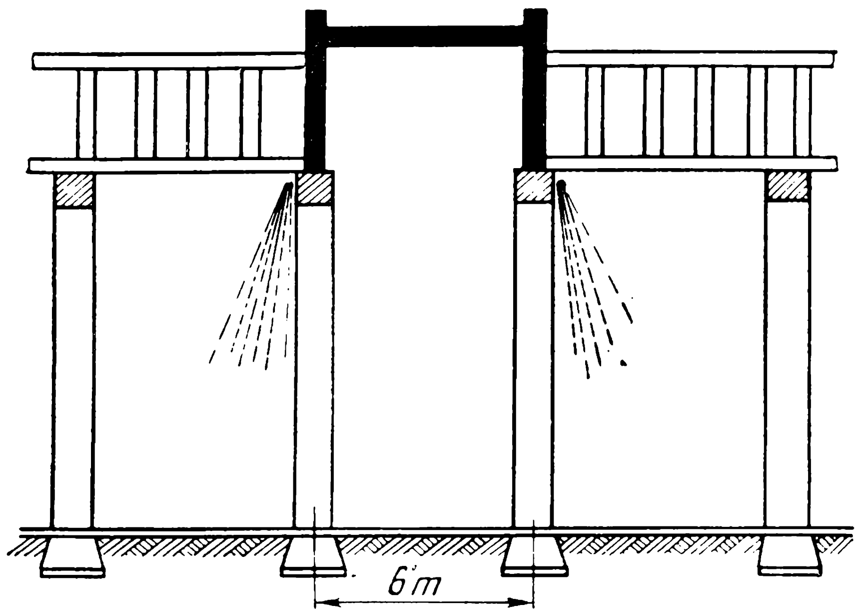

Fig. 83. A construction of a fire-check zone with fire-drenching nozzles on both sides to arrest flames and check spread of fire through building

axis of the building. The roof stoppings divide only the roof flammable structures into sections. Stand-alone fire-proof walls serve as shields against radiant heat, and are built only where the open space between the building is insufficient to ensure fire safety.

Stoppings are constructed so as to intersect the floors, ceilings and roof structures, skylights and lanterns and other structures above the roof and ensure a freeboard of not less than 60 cm over roofs from inflammable and hardly flammable materials, and 30 cm over roofs from non-flammable materials.

Doors and gates and other openings in stoppings are made inflammable or hardly flammable with a fire-resistance limit of not less than 1.5 h. The total area of such openings should not be more than 25% of the entire surface area of the stopping.

The number of stoppings is chosen proceeding from the fire-hazard classification category of the manufacturing process.

Fire-check zones are provided in single-storeyed industrial buildings where the construction of stoppings is impracticable for reasons of process technology or convenience.

Fire-check zones are strips of non-flammable materials resting on non-flammable supports. Their aim is to divide inflammable or hardly flammable floors and walls into sections not less than 6 m wide (Fig. 83). Fire-check zones can be lateral and longitudinal with at least 70 cm freeboard of the vertical walls confining the fire-check zone, above the roof of the structure.

Open space (*gaps*) between two buildings, structures or enclosed storage facilities is determined by the fire-resistance class of structures with respect to the most fire hazardous category of the process carried on inside, in accordance with Table 32.

Table 32

Fire-resistance class of structure	Open space or distance, m		
	I and II	III	IV and V
I and II	10	12	16
III	12	16	18
IV and V	16	18	20

Note. Open space (or gap width) between buildings is the distance between external walls of the one building.

The distance or open space between industrial buildings and structures does not matter when:

(a) the floor area of two or more buildings (structures) having non-flammable walls and roofs, flammable roofs over non-flammable base, or their shed area does not exceed the area permitted between two stoppings;

(b) the wall of the taller building (structure) is a stopping (wall);

(c) buildings or structures under Classes I and II regarding their fire-resistance have non-flammable roofs or inflammable roof over a non-flammable base, and incorporate processes that are under the fire-hazardous categories D and E.

The building housing processes under categories A, B and F should have light roofs that will render no resistance to blast wave (Fig. 84).

10.5. COMMON FIRE HAZARDS AND PRINCIPLES OF ACCIDENT PREVENTION

Common fire hazards include flammable liquids, open light and flames, poor housekeeping, badly maintained and hence overheated machines, electric wiring, static electricity, welding and soldering equipment and smoking. Some industries (e.g., chemicals, oil and paint manufacture) involve special fire risks.

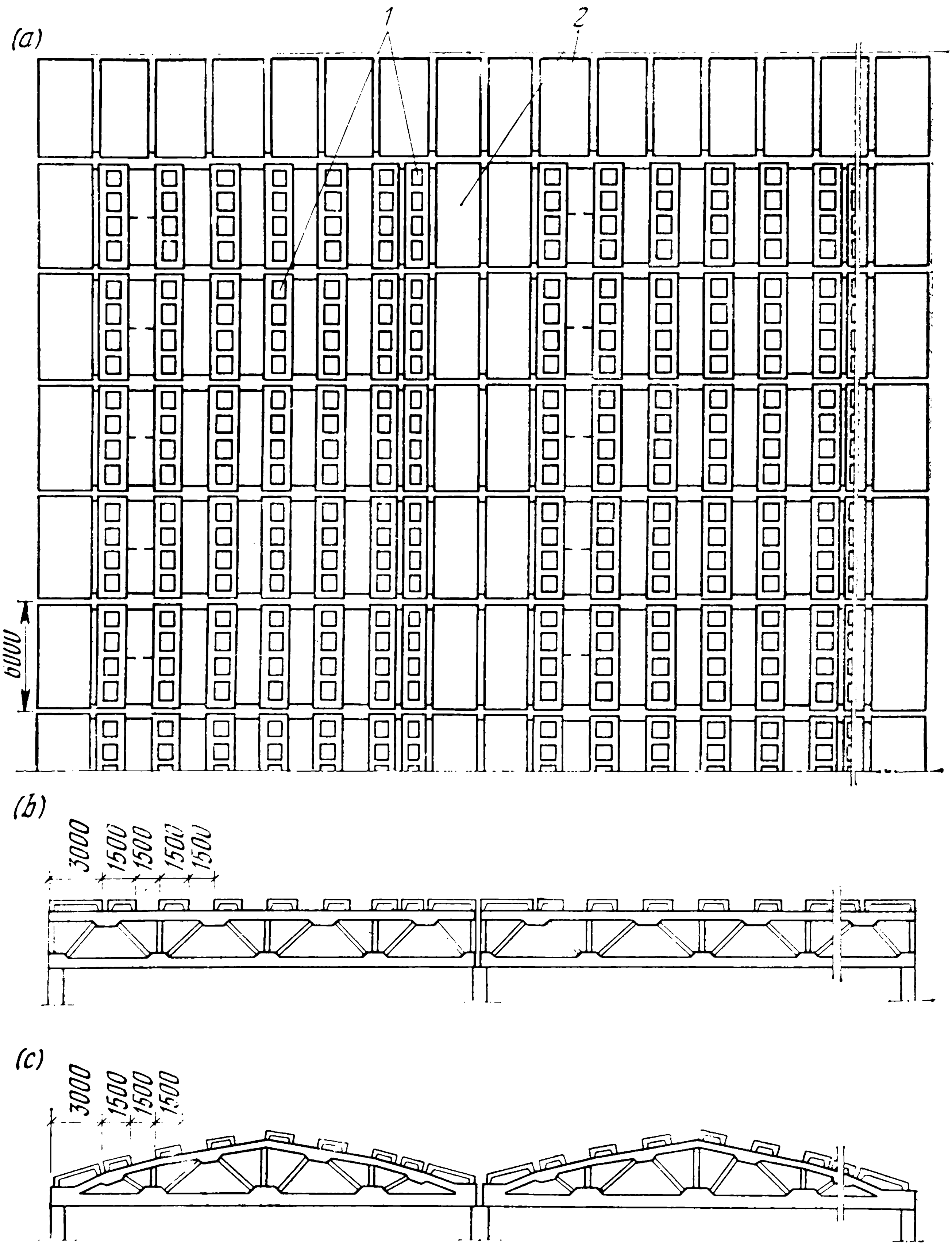

Fig. 84. A light roof with easily disposable covers

(*a*) arrangement of roofing in plan; (*b*) flat roof; (*c*) double pitch roof; *1* — roofing element with a hole; *2* — continuous roofing cover

Fire-resistant construction of buildings is very important. It should ensure that structural parts do not readily burn, fire cannot spread through the building in any direction through doors, elevator shafts, stair cases, or ventilating ducts.

Exits and escape ways. Exits are most important and should conform to the following general rules:

(1) no part of the building should be far from an exit leading to the outside, the distance depending on the degree of fire hazard (Table 33);

Table 33

Process category	Fire-resistance class	Distance to exit or escape way in buildings, m		
		single-storeyed	two-storeyed	three-storeyed
A	I and II	50	40	40
B	I and II	100	75	75
C	I and II	100	75	75
	III	80	60	60
	IV	50	30	—
	V	50	—	—
D	I and II	Not limited		
	III	100	60	60
	IV	50	40	—
	V	50	—	—
E	I and II	Not limited		
	III	100	75	75
	IV	60	50	—
	V	50	40	—
F	—	100	80	75

(2) each floor should have at least two exits, sufficiently wide, protected against flames and smoke and well separated from each other;

(3) wooden stairs, spiral stairs, elevators, and ladders should not count as exits;

(4) exits should be signposted and well lit;

(5) exits should always be kept unobstructed;

(6) outside stairways and fire escapes should not discharge into interior courtyards and blind alleys.

Escape ways in industrial building and ancillary structures are provided in sufficient numbers to ensure that the factory personnel are quickly evacuated by shortest possible ways.

Escape ways are exits that lead:

(1) from ground floor rooms outside, directly or through a corridor, vestibule or stair-case landing;

(2) from rooms on any floor but the ground-floor into a corridor or passage leading to a stair-case landing, or a stair-case provided with an exit outside, or through a vestibule;

(3) from rooms to the adjoining rooms (on same floor) having exits outside and housing processes other than under categories A, B, and F.

Each building should have at least two escape ways. In multi-storeyed buildings the distance from rooms to blind corridors leading to the nearest exit outside or to a stair-case landing should not exceed 20 m. The doors of escape ways should swing outward. Sliding, revolving or vertical-sliding doors in escape ways are inadmissible.

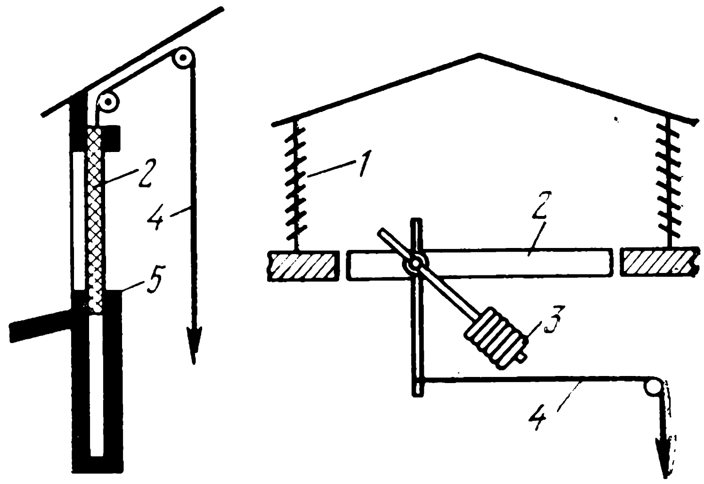

Fig. 85. A smoke cleanout (aspirator)
1 — louvers; 2 — gate; 3 — control level; 4 — pulley rope; 5 — guides

Smoke exhausts. The burning of various materials during fire generates large quantities of smoke which impairs visibility, generates large quantities of smoke which impairs visibility, blocks the ways of escape and lowers the efficiency of fire-fighting. Smoky atmosphere and high temperatures may cause asphyxia. Such accidents during rapid evacuation of people are conducive to other kinds of injuries due to jamming of the escape passages. Natural escape of smoke through windows, doors and vents may be insufficient. Ventipanes or smoke escape windows are provided in industrial building and structures to facilitate smoke removal (Fig. 85). In addition, such exhausts help rid of combustion products, prevent excessive penetration of smoke into the adjacent areas and rooms and can be used to control combustion by directing the flame as practicable for fire suppression. Smoke exhausts of this type are installed in all industrial buildings which have no skylights or lanterns, and in production premises located in the basement of buildings. Such devices may be made in the form of louvers or shutters, flaps operated manually or automatically, and also as light-weight easily disposable structures.

The section area of smoke holes depends on the room area and is determined largely by rough calculation.

Fire hazards inherent in electrical equipment. Electric energy is widely used in manufacturing undertakings in power supply units, heating installations, process equipment, machines, and for lighting purposes. There can be no special risks involved in an electric installation provided it is properly rated, maintained and operated. Fac-

tors of abnormal operation of electrical installations are short-circuiting, overload, high contact resistance, etc. The result of overloading of circuits and lines, poor contacts and improper coupling, internal defects in electrical units leading to short-circuiting is heat that deteriorates the protective powers of insulating materials and causes combustible insulation (cardboard, silk, rubber, etc.) to ignite.

The amount of heat generated (J) in a conductor is

$$Q = 0.24\ I^2Rt$$

where I is the strength of current, A; R is the electrical resistance in the conductor, Ohm; and T is the time, s.

When the strength of the passing current is much higher than that of the current for which the conductor is rated, the generation of heat intensifies and exceeds the heat losses thereby overheating the conductor and its insulation which loses its desirable properties. Overheating of the insulating materials is inadmissible and should be avoided to prevent damage and accidents. Critical temperatures for some insulating materials are:

rubber	55°C
cotton cloth	95°C, and
asbestos	115°C

To ensure fire safety all electrical networks are calculated and rated in accordance with the user rules of the operation of electrical apparatus. The rules establish proper choice of the conductor size, insulation, protection of the conductor from overload depending on the network rated load and the category and class of the room in which electric wiring is installed.

But even the properly designed, maintained and used apparatus may involve risks of fire or explosion if their current-conducting parts are exposed to combustible and readily-flammable substances and objects.

Any electrical line, apparatus or installation should be provided with protection devices that automatically cut off the power supply to a section or the whole network in the case of short-circuit or any other fault. Circuit-breakers should be designed so as to prevent arcing or sparking during their operation.

Power distribution devices may also be dangerous in the case of short-circuiting. To eliminate fire hazards, distribution cabinets are made of non-flammable materials and are installed in dry, well ventilated rooms or places free from dust or explosive air-dust mixtures.

The electric wiring for lighting installations may also present certain degree of fire risk due to overloading and overheating of conductors and insulation. Such hazards can be avoided through external protection of the electric wires from mechanical damage

by laying the conductors in rubberized or steel tubes with internal insulation.

A dust explosion may occur when a suitable mixture of flammable dust with air is ignited by a heat source of sufficient intensity, for instance when a cloud of dust is ignited by a flame, a spark or a very hot object, such as a carbon-filament electric bulb. Electric bulbs may be heated to rather high temperatures, up to 200°C and if unprotected tend to accumulate much dust on their surfaces. Dust lodged on the bulb and nearby objects may easily ignite and give rise to fire. The use of open bulbs (unprotected) in industrial buildings is therefore inadmissible and should be avoided by replacing them as far as practicable with suitable luminaires.

Fire hazards involved in static electricity. Electric charges are known to accumulate on the surfaces of certain materials (solid and liquid) and parts of equipment due to contact electrization. Potential difference is likely to result on the surfaces of two bodies brought in close contact or working in friction. The magnitude of the difference depends on the dielectric properties of the materials of these bodies, force of contact, surface moisture and temperature, and climatic conditions of the environment. When these bodies are separated, each will carry its own electric charge. The increase of the distance between the charged bodies increases the potential difference to some tens even hundreds kilovolts.

In that way, electric charges may accumulate on the moving transmission belts and pulleys, conveyer rubber belts, flowing liquids, etc. As a result, the non-grounded parts of equipment get electrized carrying a charging voltage, relative to earth, of about tens of kilovolts.

The electric charges accumulated on different parts of equipment may neutralize due to electric conduction in the humid air, and may flow from the surface in the ground. If the charge is large and the air humidity low, an instant sparking discharge between the equipment parts or into earth may turn to be sufficient to ignite a flammable material or a combustible mixture. A spark marking an electric discharge of 3 000 V is capable of igniting all the vapor- and gas-air mixtures in the room; and one of 5 000 V, most of the combustible dust and fibrous materials. In that way static electricity in the industrial environment may cause violent explosions and fires.

The accumulation of electric charges can be prevented through:

— grounding of industrial equipment and storage tanks for flammable liquids and liquid fuel;

— increasing that surface conductivity of electrifying bodies by humidifying the air or adding antistatic agents. Practically no charges accumulate at relative humidity around 85%, and higher;

— ionizing the air by applying an electric field of high intensity, or using a source of radioactive radiation.

Heating and ventilation. Normally, the central water-heating system which has no special fire risks is used for heating major production areas and ancillary premises. Finned tubular radiators which usually accumulate much dust are not advisable for use in industrial buildings because of the risk of autoignition of dust, and consequent fires.

In the central air-heating systems, the outdoor air is preheated to temperature of about 60°C before it is admitted through a system of air-ducts into work zones and, therefore, such heating units involve no special risks of fire. Potential hazards, however, exist in the air-ducts since they communicate with all rooms and separate sectors of the production area of a building and may increase the danger by spreading fire and smoke all over the building.

Local air heaters are safer as regards fire risks being installed directly in the place to be heated and requiring no air-ducts to convey the heated air.

All major production areas and ancillary premises should have either natural or forced ventilation, or both. The length of air-ducting in the horizontal plane for the ventilation systems using natural draught should not exceed 8 m, for those using induced draught, 30 m.

Local exhaust ventilation can be effectively used for the removal of harmful, explosive and flammable substances. The concentration of explosive gases and dusts in exhaust ventilation ducts should not exceed 50% of their lower explosive limits.

The best line of defence however is to prevent the formation of explosive air-gas and air-vapor mixtures or, if this is not practicable, to dilute them beyond the lower explosive limit by general ventilation, or remove them at the source by local exhaust ventilation. Prevention of dust concentrations in dust exhaust systems is in the first place a matter of proper design. Correct operation may reduce the risks still further. For example, it is advisable to keep the exhaust machinery running a few minutes after the machine it serves have stopped. In this way the ducting will be purged, and the danger that starting the exhaust fans may whirl up dangerous clouds in the ducts is eliminated. If there is a risk of dust explosions inside apparatus, the oxygen content in the air may be reduced by removing some air and replacing it by an inert gas, such as nitrogen or carbon dioxide.

The choice of materials for the ducting network depends on the medium it is supposed to transport with due regard to the properties of materials that can minimize the danger of fire or explosion.

Heating installations and processes. High temperatures achieved in industrial furnaces, driers and many other heating installations involve serious risks of fire in the cases of failure of integrity, improper operation, defects in the casings and flue-gas stacks and ducts.

Chiefly, the safe operation of furnaces is a matter of proper construction. Furnaces as a rule are installed in fire-proof buildings, and the fire-safety of the design and operating instruction take into account the kind of fuel, fuel-feeding system, type of burners, combustion control and flue-gas disposal systems.

Industrial driers may sometime be installed directly in the production department if this is practicable or cannot be avoided or otherwise solved for technological considerations. In such cases all the necessary fire precaution measures should be undertaken to eliminate or minimize fire risks due to the presence of flammable substances, or the heating process itself. Very important in this connection is the proper air exchange in the driers which can be achieved by using local and special-purpose ventilation units.

Heat treatment of products may involve quenching which is effected in quenching baths filled with mineral oils or dissolved salts. The temperature of the oil in such baths should not exceed the one prescribed for the given oil grade. Excessive oil vapors are removed by exhaust ventilation.

Production sectors housing quenching (salt) baths and similar type processes should be separated from the rest of the production areas with fire-resisting partitions or barriers. All the objects that are likely to contact with dissolved salts should be absolutely dry. The presence of even negligible amounts of moisture induces a violent evaporation, similar to explosion resulting in splashes of molten salts all around the place and in injuries and fires. Where saltpeter is used precautions should be taken not to heat it above 520°C and prevent its explosive decomposition which starts at 500°C.

Painting. The risks of fire and explosion are high in jobs involving painting, particularly spray painting operations, due to the immediate formation of explosive mixtures with air. All flammable liquids such as paints, lacquers and solvents, should never be stored in glass bottles, which have often caused fatal accidents, but always in metal containers properly sealed and placed. For each job the ready-made paint should be taken from the storage dispensing room in quantities sufficient for an 8-h work and not more; any quantities left are to be returned to the storeroom after working hours. It is advisable that all exhaust ventilation facilities, air ducts grilles, tanks and walls of the exhaust cabinets, driers and paint-spray rooms are inspected and cleaned regularly twice a month. The floors and workplaces should be kept clean and free from paint residues. The use of hand tools sparking on impact is inadmissible where use is made of nitrocellulose enamel. One very common fire precaution where the fire risk is particularly great is the "no smoking" rule.

Adhesive materials, such as all sorts of glue, cement and solutions used in woodworking departments, can be heated exclusively by applying steam; exceptions can be made for fire-proof electric heaters

and appliances designed specifically for this purpose. Glue boilers should be installed in a special place protected from fire. Smoking is allowed only in special rooms.

Spark suppression. Where solid fuel is used sparks from smoke stacks may become a problem unless spark-quenching network is provided. Fire risks are great with hot-blast cupolas in which excessive spark-formation occurs due to blasting. Sparks may be suppressed by special spark killers, i.e. spark-quenching devices and spark traps. A sudden change in the direction of flue gas in a stack facility causes the solid particles to precipitate. This principle is used in trapping sparks. There exists a number of designs of spark-trapping devices which have proved effective in ensuring fire safety of industrial undertakings.

10.6. STORAGE OF EXPLOSIVE AND FLAMMABLE SUBSTANCES

Each manufacturing plant has to have storage facilities to avail itself with a stock of raw materials necessary for a normal non-stop operation. Some of the stock items may turn to be explosive and flammable. The location and construction of storerooms and storehouses should conform to the standard requirements for fire prevention. The materials in storage should be groupped according to their properties (combustibility, reaction with water, etc.). Storage of pressure cylinders should comply with the rules for the safe construction and use of pressure vessels.

In general, the following fire-precautions should be taken in storing gases:

— storage facilities with a capacity of less than 50 cylinders should be located not closer than 10 m to industrial buildings housing manufacturing processes under the categories D and E, and not closer than 50 m to buildings with processes under the category C;

— storage facilities should be single-storeyed houses with light roofing structures, well-ventilated and illuminated, and of fire-resisting construction;

— neither storage of flammable (fuel) materials, nor jobs involving use of open flame are allowed in a 10-m distance around the gas-storage facility;

— cylinders for flammable gases can be stored in one storeroom only together with cylinders for inert gases;

— cylinders for oxygen should be stored in a specialized storeroom or storehouse separate from those for other explosive and flammable gases.

Flammable liquids can be stored:

— in rooms for container-storage of liquids (particularly where such liquids are used in large quantities);

— in above-ground tanks and
— in underground tanks.

The maximum areas for storage of flammable liquids and fuels are prescribed as follows:

Kind of liquid	Area, m^2	
	above-ground tank	underground tank
Flammable	1 000	2 000
Fuel	2 000	10 000

Large quantities of solid fuels, such as fossil coal (lignite and antracite) and peat are used by manufacturing plants for the process or heating purposes. The risks of fire involved in coal and peat are attributed to their capacity of self-igniting. Depending on the grade of coal, methods of extraction and stockpiling of peat and conditions of storage, autoignition can be fast or slow.

The dangerous (critical) temperature for coals is +60°C; at higher temperatures coal in piles heats more rapidly due to the higher rate of oxidation. To avoid heating, bituminous coals and lignites should be stored in piles not more than 2.5 m high and 20 m wide at the base; the temperature inside the pile should be regularly measured. Peat in storage is more dangerous than coal. Fine-sized peat is readily self-ignitable. The spread of flame during the combustion of peat is more fast than of coal, so fires due to peat are more violent, devastating and dangerous to the nearby buildings and structures.

Fuel storage facilities should be provided with fire-fighting equipment: fire-extinguishers, shovels, sand containers, etc., and be maintained in good shape and ready for use, if necessary.

When choosing areas for storage, it is feasible that standard safe distances be strictly observed.

10.7. LIGHTNING PROTECTION

During thunderstorms, electric charges may carry 150 000 000 volts of a current up to 200 000 A. When discharged to earth, lightning may be destructive causing violent explosions and fires in the ground structures.

The safety of people, buildings and other-type ground structures and equipment, and the protection from the destructive actions (heat, electric, and mechanical) of lightning is ensured by lightning protection.

By standard, lightning protection includes three categories of over-voltage protection devices (lightning protectors) which differ

in design depending on the cubic capacity, fire-resistance, purpose, and fire and explosion risks involved in the objects these devices are designed to protect, with due regard to the mean annual thunderstorm occurrence in the region of the given geographical locality.

Lightning protectors under the categories I and II are intended for the protection of ground objects against direct stroke of lightning, electrostatic and electromagnetic induction, from surges and high potential in the above-ground and sub-surface metallic service lines.

Lightning protectors under the category III provide protection to ground objects against direct stroke of lightning, from the accumulation of high potentials in the above-ground metallic service lines, and to apparatus from reinforced concrete and synthetic materials, and to loose roofs, from electrostatic induction.

Direct stroke of lightning is most dangerous. Lightning discharges to earth can be diverted from buildings and structures by lightning arrestors or protectors. The lightning arrestor can also be an over-voltage protection device in parallel with apparatus to be protected from surges arisen from lightning. It provides a low impedance so that the voltage reaching the apparatus is limited. The name surge-diverter is now preferred.

Usually, a lightning strikes the highest objects and particularly metal structures. So the lightning protector should be higher than the object to be protected. In this way, all objects which are within the area, called the lightning-protected zone, are saved from direct stroke of lightning with a sufficient degree of safety (99%).

Sharp changes of the lightning current initiate electromagnetic induction, creating potentials in the open metallic contours which present danger of sparking at points where the contours meet or come close to one another; this is known as the secondary effect of lightning. Lightning may also cause electric charges to accumulate in apparatus located inside the building through surges in the external metal constructions and service lines. Metal casings of electric apparatus can be protected from electromagnetic induction by connecting them to the grounds, or to a single grounding device.

Surge absorbers or modifiers which divert and partly dissipate the energy of a surge are used to prevent possible damage to apparatus or machines connected to a transmission line. Apparatus and machines are connected to the general protective grounding or specialized grounds to avoid electrostatic induction.

The lightning protector (arrestor) consists of a support, lightning arrestor, current-tap conductor, and a grounding device. There exist several types of lightning arrestors of which the lightning-rod and lightning-conductor protectors are most common. These can be stand-alone or roof-mounted structures (Fig. 86). The *rod-type arrestor* consists of one or more vertical rods installed on near the structure

to be protected. The *conductor-type lightning* protectors are one or two metal wires fixed horizontally between two supports carrying current-tap conductors connected to the grounds. Lightning arrestors are round steel rods, pipes or ink-plated (galvanized) steel wire, etc.

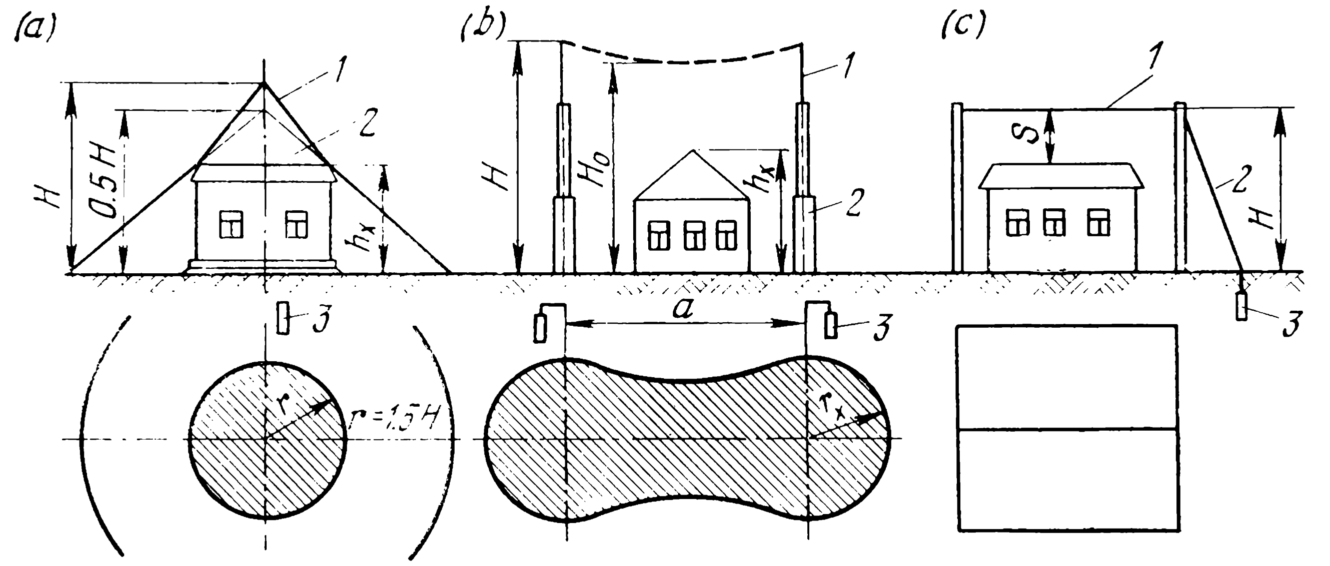

Fig. 86. Types of lightning protector and protected zones
(*a*) stand-alone lightning rod; (*b*) double rod arrestor lightning; (*c*) conductor-type lightning protector; *1* — arrester; *2* — current-tap; *3* — grounds

Current-tap conductors are made of steel wires of a section not less than 35 mm^2. All current-conducting parts of a lightning protector are welded.

The grounds can be steel strips or pipes either buried or driven in the ground, or made as combination of both.

The strip-type (or horizontal) grounds are one or several steel strips 30 m long laid at a depth of 1 m and more. The vertical-type grounds are pipes 2-3 m long driven into the ground at a depth of 0.7-0.8 m (to the upper end of pipe). The resistance of the grounding device should not be more than 10 ohm for stand-alone lightning protectors under the categories I and II, and not more than 20 ohms for those under the category III.

10.8. FIRE-ALARM SYSTEMS

One major aim of an adequate fire-prevention organization is to detect fire in due time and immediately warn people and inform the public fire station about the place of fire. This aim is achieved by the provision of an effective fire-alarm signalling system. The fire brigade can be warned about a fire through a dial telephone system connected to the fire-brigade either directly (through the public telephone system) or through a switch-board operator by dialing 01, an easy number to call the fire brigade.

In a factory, an alarm system should be available to warn everybody in case of fire. If the alarm is not given automatically this can

be done by installing alarm bells, whistles or sirens in different parts of the factory, and push-button or handles in all workrooms to operate the alarm, if necessary. Alarms must be audible everywhere including workrooms, storehouses, gangways, locker-room and washrooms.

Specialized fire-alarm systems are however most efficient in providing immediate warning about the exact location of fire. One such system is the electric fire-alarm signalling system (EFS). In some cases, this system operates the automatic means of fire-fighting.

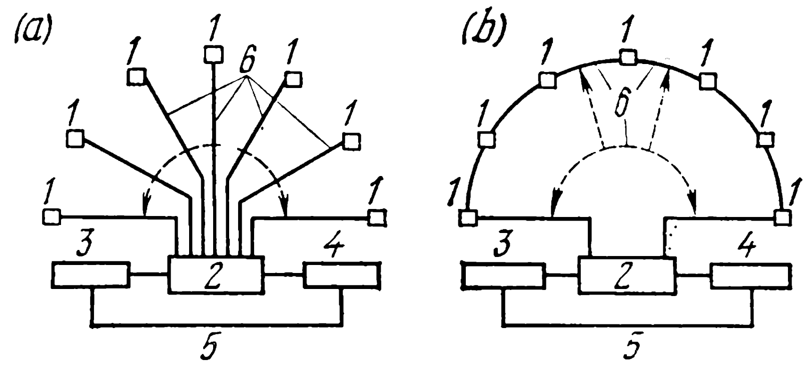

Fig. 87. Electric fire-alarm systems

(a) radial-line; (b) closed loop; 1 — detectors; 2 — receiving center; 3 – standby power unit; 4 — operating power source (mains and transformer); 5 — power switch-over; 6 — electric lines

It consists of fire-detectors (transducers), a power source, and a fire-alarm center (station) connected electrically. Electric fire-signalling system can be of two types: the radial-line and the closed-loop system (Fig. 87). In a radial-type fire-alarm system each transducer is connected to the receiving station by a separate two-wire (out- and in-going) line. The receiving station is designed similarly to a telephone switching center to receive all the signals from fire-detectors. The system has proved reliable and effective as it provides simultaneous reception of signals from all lines. It has almost replaced the closed-loop system of fire-signalling which will not be discussed here.

Fire alarm warning devices, called fire-detectors, are in fact transducers that convert the physical quantities characterizing fire into electric quantities, i.e. signals which are collected at the receiving station. The signal can be initiated manually (push-button) or automatically as soon as the parameters of the environment change due to fire (temperature, flame, smoke). Fire alarms can be *heat*, *smoke* and *light detectors*, or detectors that use more than one parameter, such as heat-smoke sensitive detectors.

According to the principle, the fire-detectors are designed to operate on alarm, distinction is made between the maximal, differential and maximal-differential types of detectors. The *maximal-type fire detectors* are designed to operate as the temperature in the room reaches the preset value (+60 or +80°C regardless of the rate

at which the temperature rises). Time of response is up to 2 min. Controllable area is up to 15 m^2.

The differential-type detectors operate as the rate of temperature rise reaches a preset value, e.g. constitutes 30°C per not less than 7 seconds. Controllable area is 30 m^2. The maximal-differential fire-detectors have a time of response of not more than 50 s and control an area about 25 m^2.

There exist several types of heat detectors of which the principal ones are shown in Fig. 88. The disadvantage of these detectors is their relatively long time of response which may be delayed by

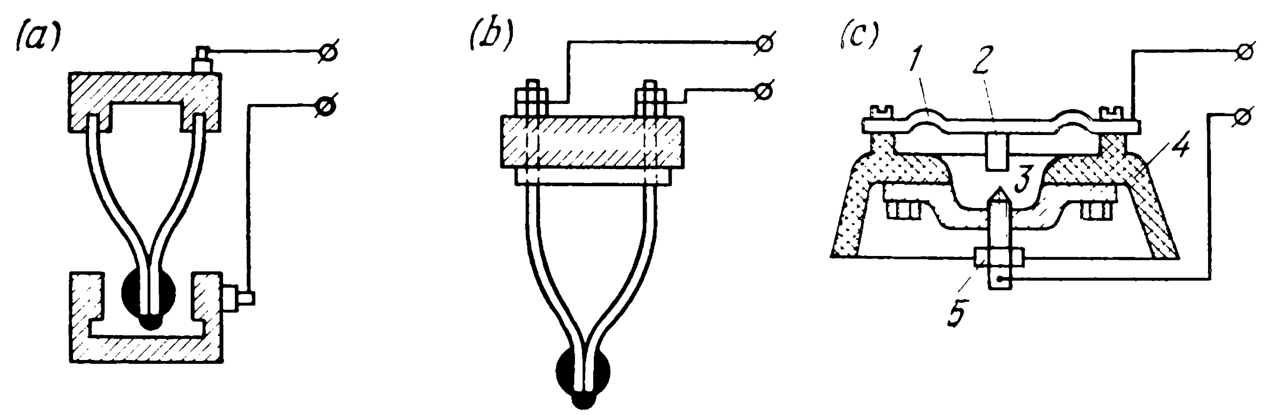

Fig. 88. Heat detectors

(*a*) fusable, normally open; (*b*) fusible, normally closed; (*c*) self-setting; *1* — bimetallic plate; *2*, *3* — contacts; *4* — insulating base; *5* — adjusting screw

several minutes. There are however quick-response heat detectors that ensure an instantaneous warning at the very onset of fire or even when the environmental changes preceding fire such as flashes, flames, sparks or smoke are inconspicuous. This is ensured by using photocells, ionizing chambers, semiconductors, thermocouples, etc.

Some heat detectors are thermocouple devices the operation of which depends on the difference in temperature between the junction of two dissimilar metal conductors. In a closed circuit, this temperature difference generates an emf, called thermoelectromotive force, which produces a thermoelectric current. The magnitude of the thermoemf depends on the nature of metals and difference in temperature. A combination of two dissimilar metals having a junction which can be maintained at the temperature which it is desired to measure in terms of the thermoelectric current produced is known as a thermocouple. An individual thermocouple produces a small thermoemf of several millivolts. To increase the thermoemf a number of thermocouples are connected in series or in parallel or both to form a thermopile.

Some heat fire detectors use a temperature-sensitive resistor with a negative temperature coefficient. Heating increases its resistance due to increased number of free charge carriers. Resistors are nor-

mally fabricated from oxides, sulfides, and metal carbides (iron, nickel, manganese, tungsten, magnesium, titanium).

Smoke detectors employ photo-cells or ionizing chambers or differential photo-relays. Ionizing chambers using α-rays proved most popular. The ionizing power of α-particles is higher than of β- or γ-rays and less harmful to the human body.

Light-detectors are designed to respond to different regions of the open flame light spectrum. Most popular are light detectors which respond to the ultra-violet region of the optical spectre and which may include thermoresistors, photo-cells, photoresistors or photo-counters, etc.

Fire alarm receiving stations or centers are designed to monitor and detect faults in the circuits, receive "Alarm" signals, and to actuate automatic fire-fighting devices and installations.

Radial-type optical fire-alarm station is designed for use in industry. It consists of a receiving unit with a power source and 10 radial terminals connected to it electrically. The number of fire detectors on each terminal is not limited. The center receives alarm signals, checks the circuits for faults, warns the fire-brigade, and operates automatic fire-fighting.

Radioisotope (fire-guard) stations employ smoke detectors, light and audible fire alarm indicators and are intended for use in industry. One such station is capable of initiating a fire alarm, controlling automatic fire-fighting and guarding premises against trespassing by controlling the integrity of the interlocking loops and giving audible and light signals as soon as the contacts of the loops are closed.

Automatic fire alarm-guarding stations are designed to detect smoke, heat and open flames, indicate places of fire and warn the fire brigade by light or audible signals. Such stations can also operate automatic fire-fighting, and safeguard the premises.

Photoelectric fire alarm-guarding system is intended to receive and register fire-alarm signals coming from smoke detectors. It operates automatic fire-fighting and an audible alarm.

The system ensures that a warning "Attention" is given after one fire-detector operates, then it starts an "Alarm" and automatic fire-fighting after two or more fire-detectors have operated. The system monitors and checks all the circuits and detectors, received the signals and transmits the information to the central fire control board.

Concentrators of the fire-guard signalling system safeguard the industrial premises against trespassing, and fire. Using one receiving station the system serves the dual purpose of giving fire-alarm warning and safeguard signalling.

All industrial buildings incorporating production departments, workshops, laboratories, storehouses and rooms for raw materials and finished products should have a fire alarm system installed and properly maintained.

10.9. SUPPRESSION OF FIRE AND FIRE-FIGHTING EQUIPMENT

The aim of fire-fighting is to extinguish or suppress the fire by creating conditions in which burning can no longer continue.

In fire-fighting it is necessary to take into account that the rate with which flame spreads over the surface of solids is about 4 m/s, and over liquids, 30 m/s.

The combustion products are dispersed solid particles, vapors and gases. Their temperature depends on the heat and rate of combustion and flame spreading, size of building and supply of air. High-temperature smoke promotes spread of the combustion products through the building, deteriorates visibility and makes fire-fighting difficult. Large quantities of inert and flammable gases are generated during fire. The composition of explosive gases most of which are toxic or corrosive depends on nature of materials and the rate of burning. Most toxic and corrosive gases are produced during the burning of fire-retardant materials (ammonium bromide, chlorine, etc.), wood (carbon monoxide), polymer construction materials, and other building products.

The products of incomplete combustion spreading through the building on fire may ignite due to high temperature and presence of air and facilitate ever more spread of fire.

Principles of fire suppression. Fire can be suppressed through:

— cooling the burning materials with substances of great heat capacities;

— cutting short the supply of air to the surfaces of burning materials;

— reducing the content of oxygen in the air;

— using special chemical compounds.

Fire suppression with water. Water has been recognized as the cheapest, always available and effective means of controlling fire. Its heat capacity is so large that it is able to remove heat from the burning materials and reduce the temperature at the site of fire to that at which burning is no longer possible.

It is known that heating 1 liter of water to 1°C requires 4.2 kJ. When water is used in fire-fighting, 335 kJ of the heat of combustion will be spent to heat 1 liter of water from 20°C (room temperature) to 100°C (boiling temperature). Then, transferring water from the liquid state to vapour will require 2 260 kJ more of the latent heat of vaporization. Vaporization of 1 liter of water generates 1 700 liters of steam which block all access for the air to the burning materials thereby facilitating fire suppression.

However, water cannot be used for fighting fire in which substances such as potassium and sodium are involved since these readily enter into reaction with water even at low temperatures to replace

hydrogen in it, and hydrogen-air mixtures are highly explosive. Neither can water be used in fighting fires on energized electric apparatus because this will involve the risk of electric shock for the fighter. It is inadmissible to use water on calcium carbide for danger of explosion of acetylene rapidly evolved on contact of water with calcium carbide.

In fire-fighting, water is used in the form of jets or sprays, atomized droplets, and foam. High-velocity jets of water directed on the site of fire physically knock off the flames cooling at the same time the burning materials. Fire-fighting can be effected from long distances to the place of fire which is important where heat radiation is high and a closer approach to the site of fire is difficult, if not dangerous. However, the application of water jets of high intensity is not always practicable. It is unadvisable to use jets of water on flammable liquids because this may cause spread of the water solution and hence extend the zone of fire.

Surface contact of water with the burning materials is increased substantially if the water is sprayed or atomized to a drop-size of less than 0.1 mm. The vaporization of so many droplets will require more heat from the burning material thereby promoting the cooling and suppressing of fire. Sprays of water are effective in reducing the environmental temperature during fire and suppressing smoke. The water is sprayed from the ceiling and is distributed so as to be spread over as large an area as practicable to extend the pathways of the water drops through the smoke and fire. Fine drops of water heat up and vaporize, large drops heat up and absorb the gaseous and solid products of combustion. This reduces the temperature in the room on fire. The smoke sediments and subsides making the place of fire visible and accessible.

Sprayed water can be effectively used to control fires of petrochemical products with a flash point above 120°C.

The addition of foaming agents in quantities of 0.2-2.0% (by mass) into water reduces the surface tension of water, improves its fire suppression properties, reduces 2-2.5 times the flow rate (discharge), and speeds up fire-fighting.

Fire suppression with steam. Plants in which steam sources are sufficiently large can use steam for fire-fighting purposes. Fire suppressive action of steam is based on its ability to replace air from the enclosure when its concentration per unit volume is high. Excessive moisture and the cooling effect of steam in fire-fighting are not to count. The room in which fire is to be suppressed should be quickly filled up with steam (in about 5 to 10 min). The temperature in the room should be raised up to +85 °C. This reduces the oxygen content in the air to 15-16%, i.e. by 31%, and the burning ceases. All doors to the rooms, windows and other openings in the walls and ceiling should be tightly closed except for an open area in

the floor of about 0.5 m^2 per each 1 000 m^3 roomspace to let the air out.

Water supply. Fire hoses with nozzles should be available where practicable near water supply sources, and it is important that the connections fit the equipment of the public fire brigade so it can effectively operate in the undertaking. Factories where the risks of fire are great usually have water supply from the public piped water systems in which water under pressure is carried in pipes and is available at the factory from hydrants or emergency water reservoirs and tanks in which water is stored for such purposes. Free head of water in the low-pressure water supply system should not be less than 10 m. High-pressure waterpipe systems should be able to provide a jet of water to a height of not less than 10 m at full rate of discharge and a sufficient range for a high-pressure fire-fighting hose (barrel) elevated to the highest point of the building. Where required, the necessary head is ensured by a pump unit or an elevated water tank or tower of the appropriate height.

Water flow discharge ranging from 10 to 40 liters per second for one site of fire (see Table 34) for external fire-fighting is rated

Table 34

Fire-resistance class of the building	Fire- hazard category	Water discharge, liters per second, for building, thou cu m capacity						
		up to 3	3-5	5-20	20-50	50-200	200-400	min 400
I and II	D, E, F	10	10	10	10	15	20	25
I and II	A, B, C	10	15	15	20	30	35	40
III	D, E	10	10	15	25	—	—	—
III	C	10	15	20	30	—	—	—
IV and V	D, E	10	15	20	30	—	—	—
IV and V	C	15	20	25	40	—	—	—

proceeding from the class of fire-resistance of the building, fire-hazard category of the processes carried on in it, and cubic capacity of the building.

In buildings divided into sections by fire stoppings, water discharge for fire-fighting is rated for each section separately depending on its cubic capacity.

The number of fires (sites of ignition) that can be assumed to occur in one plant at one time depends on the production area of the plant and is adopted to be one fire for an area of 100 ha, and two fires for areas exceeding 100 ha. It is accepted that time required to control a fire at plant is 3 h.

Water discharge necessary to extinguish a fire inside a building is also standardized and should be determined in accordance with the principles given below.

Where the necessary supplies of water for fire-fighting from the mains are technically or economically impracticable, emergency water supply should be provided (stored or otherwise ensured) for a 3-h continuous fire-fighting at the highest rate of discharge.

External water supply networks should be closed systems in which water is fed from the mains and circulates in two pipelines. Hydrants are provided at an interval of not more than 100 m and not closer than 5 m to buildings and road junctions.

Internal water supply network should be available in industrial buildings except for those under the fire-resistance class I and II with processes under the categories D and E regardless of their cubic capacity, and buildings under the classes III and V with processes under the categories D and E and cubic capacity below 5 000 m^3. Provision for a waterpipe system can also be avoided in storehouses for metal materials, moulding earth and other non-flammable materials, and in some other special cases.

The water discharge for fire-fighting inside buildings is rated so as to ensure two water jets each with a flow rate of not less than 2.5 l/s. The head of water in internal water supply network should ensure a range of water jets to a height of not less than 6 m.

Fabric fire hoses should be provided with nozzles and available at each internal hydrant that is placed 1.35 m above the floor, and should be 51 and 66 mm in diameter and 10 and 20 m long. Hydrants should be located so as to ensure that the water jets from two adjacent hydrants could meet at the highest and most distant point of the building.

Fire suppression with foam. Foam is a suspension, often colloidal, of a gas in a liquid. Foam can be produced chemically using reactions of alkaline and acid compounds in the presence of a foaming agent, and mechanically by mixing and agitating foam-carrying water with air.

A chemically produced foam usually contains 80% carbonic gas, 19.7% liquid (water), and 0.3% foaming agent; a mechanically produced foam includes 90% air, 9,6% liquid (water) and 0.4% foaming agent.

In fire-fighting foam is indispensable on solid substances and flammable liquids with a specific weight of less than unity. The fire-suppressive action of foam is in that it forms a vapor-impermeable layer of a particular structure and stability on the surface of a burning liquid. Its stability is due to a considerable viscosity of suspension and a density that is lower than that of the flammable liquid. The layer isolates the burning liquid from the air oxygen and heat sources, and inhibits the evolution of toxic vapors and

gases. Of a low heat conduction, foam prevents heat transfer from the zone of fire to the burning surfaces. Chemically produced foam is widely used in portable fire extinguishers. Foam is produced mechanically in (air-) foam generators and foam mixers (Fig. 89) by mixing 4-6% water solutions of foaming agents with air.

Foams used in fire-fighting are characterized by the multiplicity and stability. Multiplicity of foam is the ratio of the volume of foam to that of the liguid from which it is formed. *Multiplicity* of a chemically produced foam is 5, that of a mechanically produced foam, 8-12, 100 and even more. The *stability* of foam is its capacity to preserve its structure at high temperature, and with time. The stability of a chemical foam is more than 1 h, that of mechanically produced foams, up to 30 min.

Depending on the risk of fire, all substances can also be characterized as regards their behavior toward various means of water-foam fire extinguishment. Water and foams are most popular means of fire-fighting but should be applied with care because their application may sometime present danger due to splashes, violent boiling and other undesirable reactions.

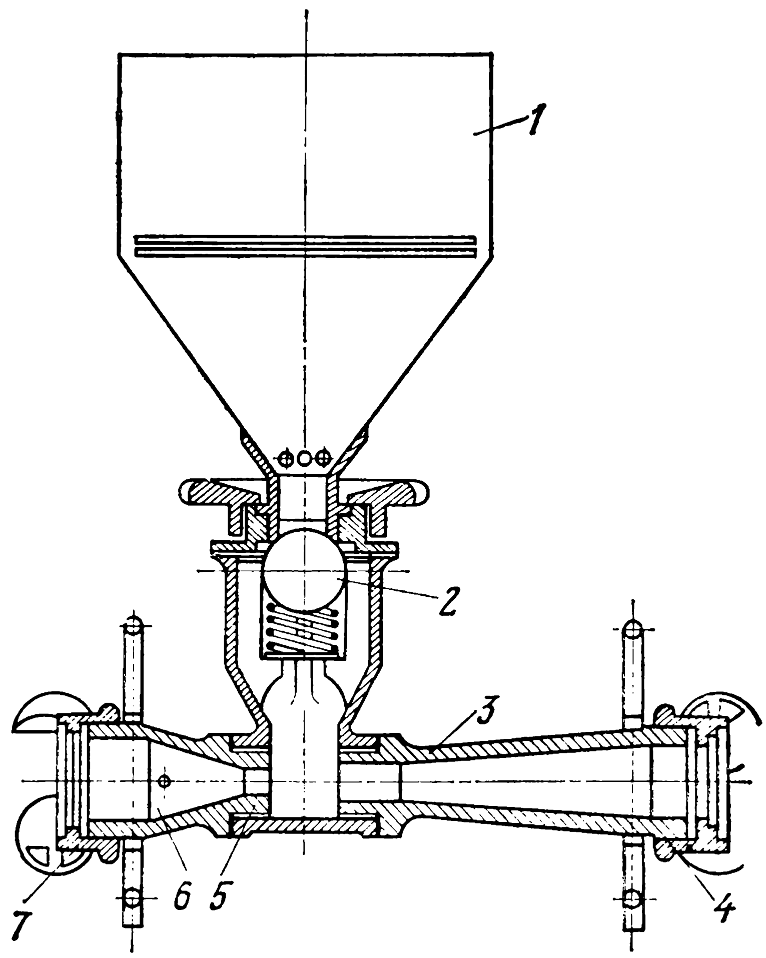

Fig. 89. A foam generator
1 — bin; 2 — globe valve; 3 — diffusor; 4 — outlet branchpipe; 5 — nozzle; 6 — inlet branchpipe; 7 — coupling unit

Foam can be produced in stationary and portable foam generators known as fire-extinguishers. Portable fire-extinguishers have found wide application due to:

— ready for use charge of fire-fighting substances;

— simplicity and prompt action;

— easiness with which one person can operate the device;

— sufficient range enabling the fighter to quickly and efficiently suppress fire at the source.

The fire-extinguisher shown in Fig. 90 is used for fire suppression over an area of 1 m^2. It consists of a steel cylinder with a capacity of 10 liters closed with a cast-iron lid on which an actuating device is mounted. The cylinder is charged with an alkaline solution (sodium bicarbonate with melting extract and water) and an acid solution

(sulfate of iron oxide and sulfuric acid) the interaction of which gives 90 liters of foam sprayed at a range of 6-8 m for 60 s. The charges can be of two types: one for summer use, freezing at 0°C; and the other for the winter use, freezing at —20°C.

Stationary foam-producing units are practicable for plants where compressed air is widely used and produced for process purposes.

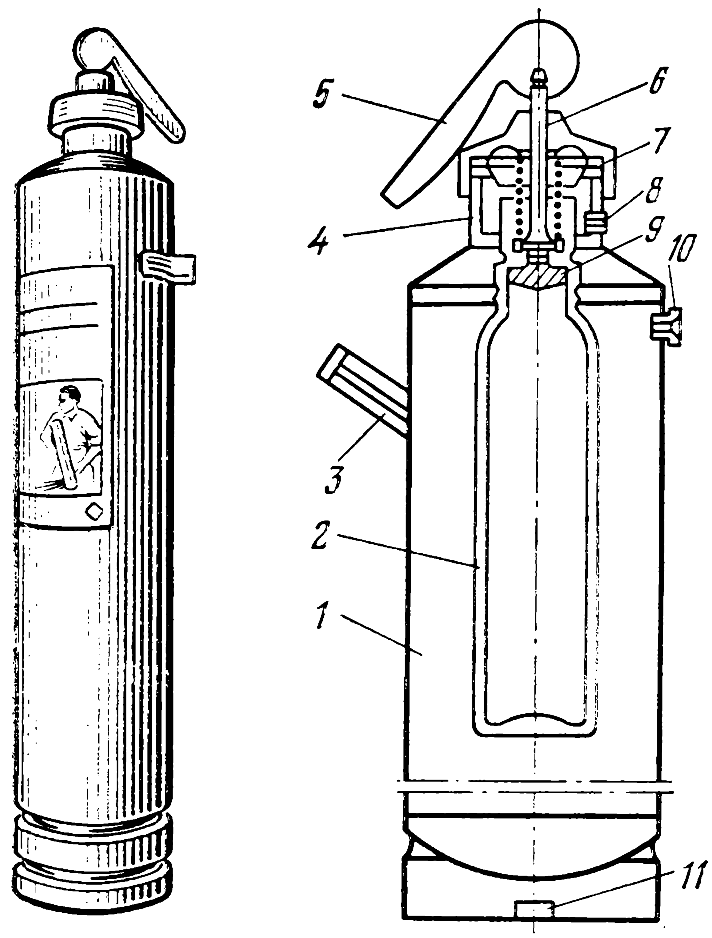

Fig. 90. A (foam) fire extinguisher

1 — cylinder; *2* — acid container; *3* — side handle; *4* — neck; *5* — control handle; *6* — rod; *7* — lid; *8* — spray; *9* — valve; *10* — release valve; *11* — bottom handle

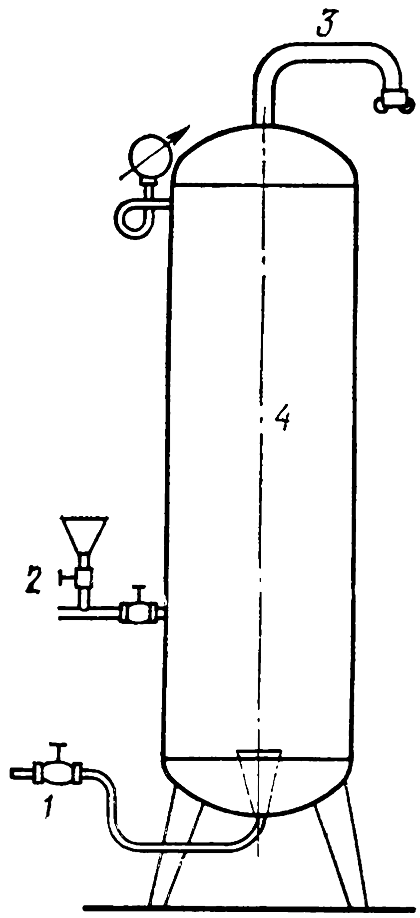

Fig. 91. A stationary foam generator

1 — compressed air feed; *2* — foaming agent feed; *3* — foam outlet branch-pipe; *4* — tank for foaming agent water solution

The tank of such unit (Fig. 91) always contains a water solution of a foaming agent and is connected to a compressed air source controlled by a valve. This foam generator is also provided with a smooth pipe-nozzle hose for delivering foam to the site of fire. The use of fire-extinguishing units of this kind is most practicable where the risk of spillage of flammable liquids of liquid fuel is great. Such foam fire-extinguishing generators with a capacity of 250 liters can produce up to 2 m^3 of foam, i.e. enough to cover an area of 10-20 m^2 with a 10-20 cm thick bed of foam.

Fire suppression with carbon dioxide gas is based on the reduction of the content of air oxygen in the site of fire to concentrations at which combustion ceases. Carbon dioxide gas is effective for a quick

extinguishing of small outbreaks of fire (within 2-10 s) and particularly where a fire breaks out over small surfaces of spilled flammable liquids, e.g., at engine test grounds, in driers, electric motors and similar electric apparatus carrying a voltage. Carbon dioxide gas supplied in quantities of 20-30% by volume of air into closed rooms is effective to suppress fire at the very onset. However, it is ineffective on substances which can burn without air, and in such cases

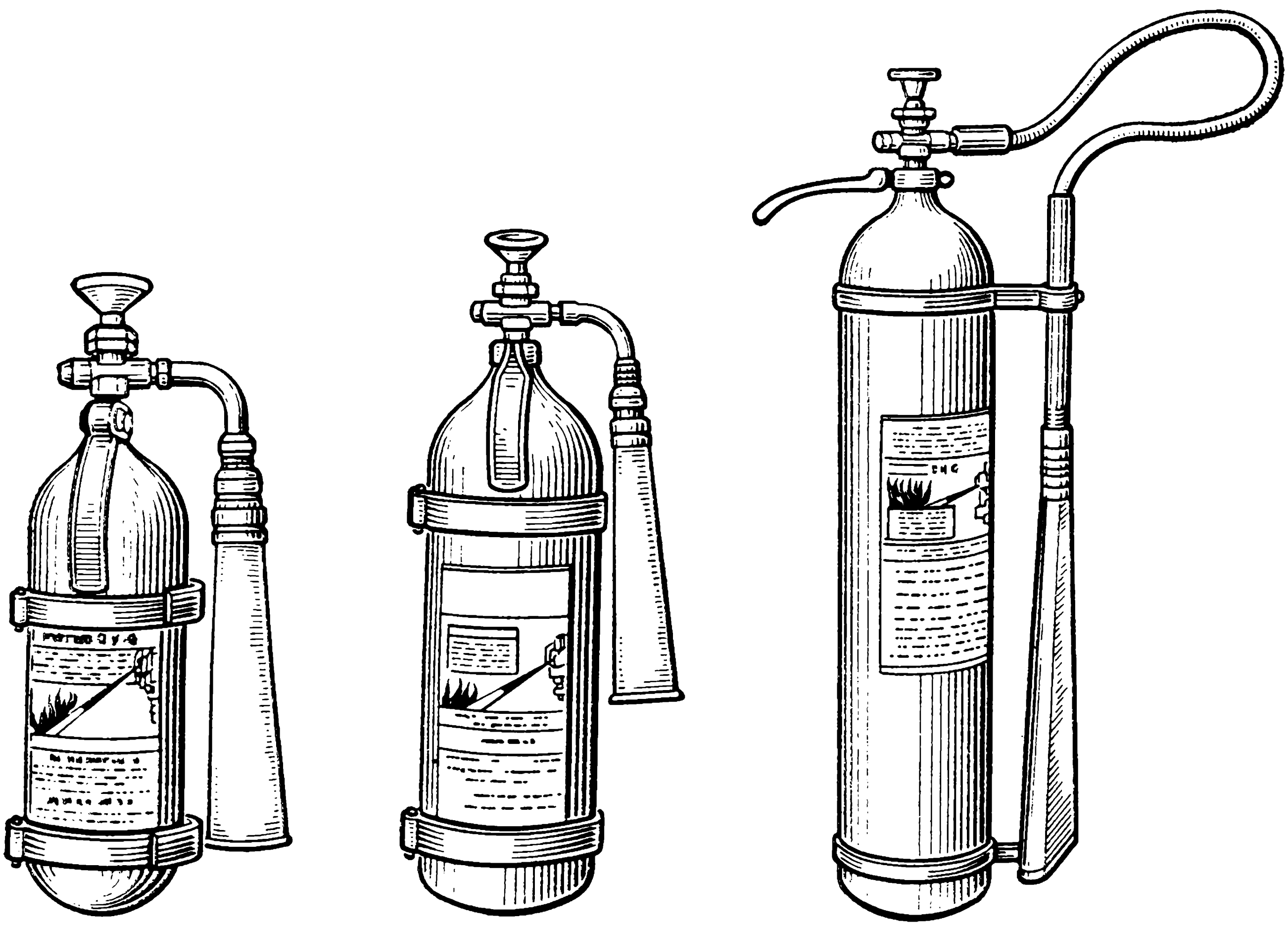

Fig. 92. Carbonic acid fire-extinguishers

nitrogen or argon are used. Fire extinguishers of various capacities are shown in Fig. 92. One such extinguisher consists of a steel cylinder, a globe valve with a handwheel, a funnel, a safety device of a membrane type, and a bracket for hanging the device on the wall. Apart from this, other types of fire extinguishers are available (Fig. 93), some of which can have two cylinders to increase the capacity and a hose of flexible pipeline connected to a cylinder with the one end and having a funnel at the other. The funnel is directed onto the burning object and the valve is opened by turning the handwheel. The liquified carbon dioxide gas is pressed out from the upper portion of the cylinder and through a siphon and valve enters the funnel where it immediately vaporizes. Vaporization is accompanied by heat absorption and this sharply lowers the temperature in the funnel. In the funnel, the liquified gas partly turns into the

solid state, the so-called carbonic snow with a temperature of —79°C. The rest of the gas keeps vaporizing and transporting snow further into the site of fire. This lowers the temperature of the burning substance and reduces the content of air oxygen in the combustion zone.

Carbonic acid-brominated ethyl fire-extinguishers are usually used in rooms housing valuable equipment which it is desirable to save from fire and protect from damage with other fire-fighting means (Fig. 94).

Fire suppression with special chemical compounds. It is difficult to extinguish burning metals such as potassium, sodium, lithium,

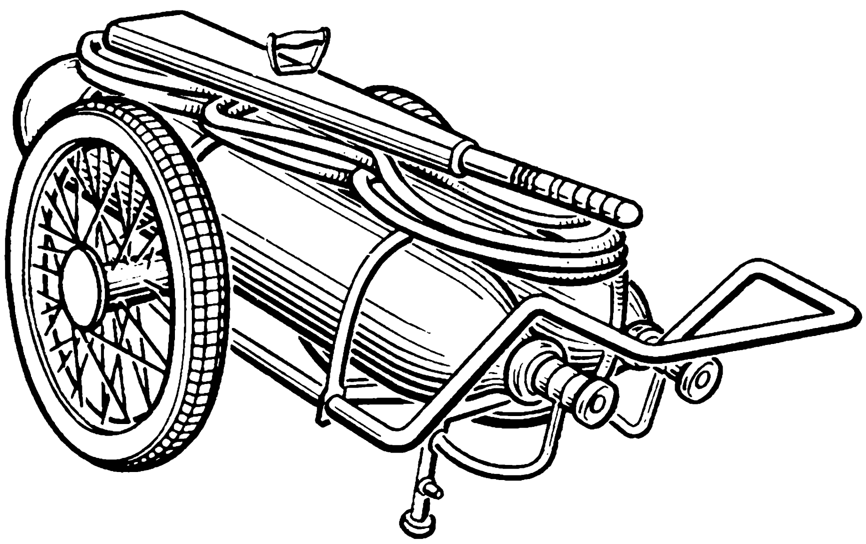

Fig. 93. Two cylinder cart-mounted carbonic acid fire-extinguisher

zirconium, uranium, thorium, titanium and magnesium. Carbon dioxide promotes the burning of magnesium. It is inadmissible to use water on burning metals for fear of explosion and danger of flying particles of molten metal over large distances.

Sand (even dry sand) enters into reaction with burning metals and may promote combustion. Where fire extends over large areas, sand at high temperatures dissociates giving free silicon, silica compounds and toxic gases. Fire-suppressing dry powders of sodium bicarbonate, sodium chlorate, pulverized graphite, magnesium carbonate, magnesium oxide or mixtures of these are normally used against fire on burning metals. Liquified inert gases have too proved effective.

Dry ground flux normally used in the melting of magnesium alloys is an effective means of extinguishing fires. Flux forms a liquid film over the metal surface thereby isolating it from the air.

Powder fire-extinguishers employ solid fire-suppressing substances, such as chlorides of alkali and alkali(ne)-earth metals, sodium carbonate and bicarbonate, etc. (Fig. 95). The suppressive action of pow-

ders lies in the isolation of the site of fire from the air and the production of carbon dioxide gas on heating.

Where the cause of fire is piped gas, the primary measure to control fire is to cut off the gas supply.

As regards portable fire-extinguishers, care should be taken that they do not constitute a danger in themselves. This is sometime the case with appliances of unsuitable construction containing chemicals

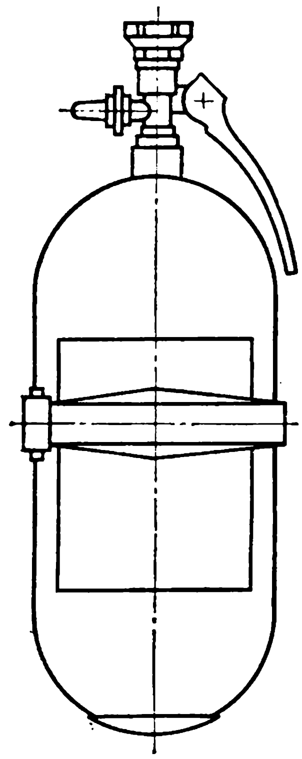

Fig. 94. A portable carbon acid-brominated ethyl fire extinguisher

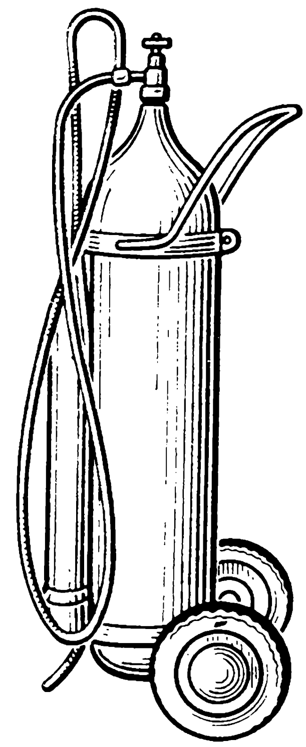

Fig. 95. A portable powder fire extinguisher

which may block the supply nozzle. When such an appliance has to be used the chemicals inside are mixed either by breaking the seal or just by turning the extinguisher upside down. The pressure inside the cylinder then increases forcing out a jet or spray of extinguishing material. But if the nozzle is blocked, the appliance will burst. Suitable construction and regular checks should prevent these accidents. Another serious risk arises when extinguishers are filled with a toxic substance such as methyl bromide or carbon tetrachloride; there will be a risk of poisoning if the extinguisher leaks or is used in a confined space. Such extinguishers should not therefore be used indoors.

So, the fire-extinguishing equipment may range from buckets of water or sand to more complicated systems, such as sprinklers. The kind and amount of required equipment depends on the size and construction of the building to be protected and on the processes carried on in it. Sometimes it is sufficient to have portable fire extinguishers, or even a supply of dry sand or some barrel of water. For

the kind and amount of fire-fighting equipment needed see Table 35.

Automatic fire-fighting. Plants in which the risk of fire is indeed great should be equipped with spinkler systems, in which

Table 35

Production area	Size unit, m2	Fire extinguishing means, pieces per equipment unit or unit area					
		extinguishers			sand bucket	water barrel	felt
		foam	powder	carbonic acid			
Metal-working machine shops & assembling depths	600	1	—	—	—	—	—
Forge & press working shops using:							
gas & solid fuel	600	1	—	—	—	—	—
liquid fuel	Each unit	—	1	—	1	—	—
Vehicle garages	100	—	1	—	1	—	1
Gas & electric stations & tin smitheries	200	1	—	—	1	—	—
Heat-treating departments using:							
solid fuel	300	1	—	—	—	—	—
liquid fuel	Each unit	—	1	—	1	—	—
Painting shops	100	—	1	—	1	—	—
Woodworking & pattern shops	100	1	—	—	1	1	—
Engine works assembling & disassembling shops	100	—	1	—	1	—	—
Acetylene filling substations	100	—	1	1	1	—	—
Transformer substations	100	—	1	—	1	—	—

Note. The kind and amount of fire-fighting equipment is determined separately for each floor and workroom of the building.

water under pressure is carried in a network of pipes installed near the ceiling of workrooms. The pipes have (at frequent intervals) spray nozzles protected with strips made of fusible alloys; these in the event of a fire melt and release water into workrooms for automatic fire-fighting. Simultaneously with the water discharge, the system operates an alarm.

Normally, major production shops and departments in manufacturing industries do not involve serious risks of fire and therefore requires no complicated sprinkler systems.

Depending on the fire-hazard class of building, the spray nozzles in a sprinkler system should be distributed, so that one spray nozzle will cover an area of 6 to 9 m^2.

The water in a sprinkler system should always be under pressure which can be maintained either by the mains pumping unit or with the help of an elevated water tank or compressed air vessel so as to

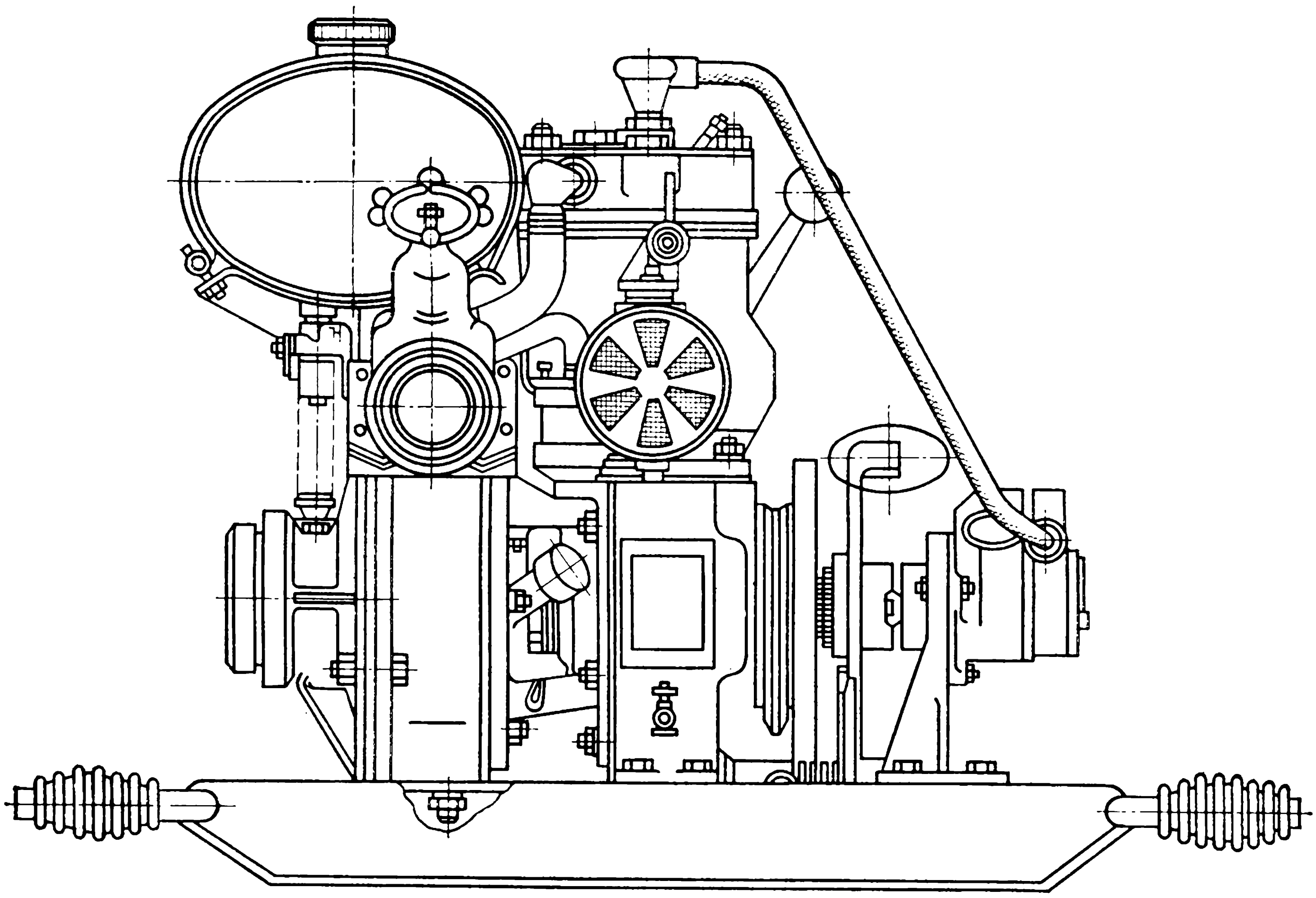

Fig. 96. A portable fire pump

ensure a discharge intensity of 10 liters per second during 10 min. If such intensity is insufficient, the main pump (Fig. 96) must be brought into operation which alone should be capable of discharging with an intensity of 30 liters per second per 1 hour (this corresponds to a discharge required by 25-27 spray nozzles opened simultaneously).

Sprinkler installations can be of three types, namely the water-filled, the dry-pipe, and the alternate type sprinkler. In the water-filled type of a sprinkler installation the entire network of pipes carries water permanently. The system is preferred for heated buildings. With the dry-pipe type of sprinkler, all pipes are filled with compressed air which, in the event of a fire is released to admit water.

The system is largely used in unheated buildings. The network of pipes in the alternate type sprinkler is filled with water in summer, and with compressed air, in winter time.

The spray nozzle (Fig. 97*a*) is an important element of a sprinkler installation. It is a ring-type head designed to be screwed in pipes from one end, and having a brass ring fixed at its other end to hold up a thin, center-hole metal diaphragm against the base of the head. A U-link is fixed to the brass ring from below to carry a deflector

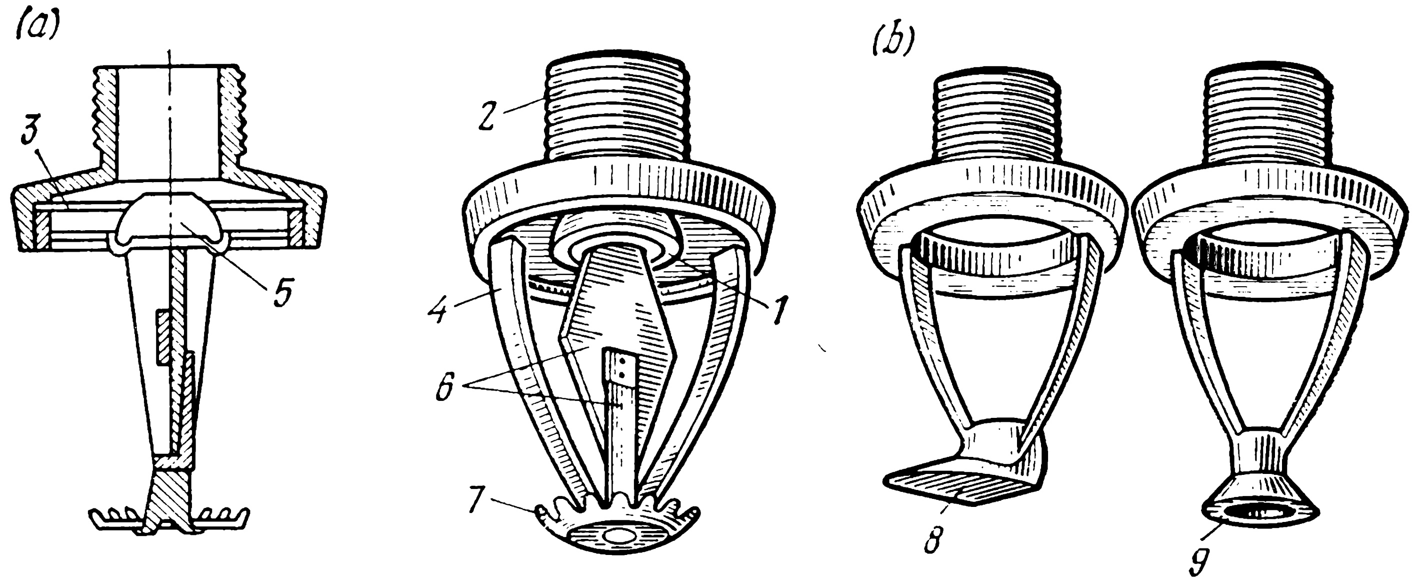

Fig. 97. Sprinkler (*a*) and fire-drencher (*b*) nozzles
1 — valve washer; *2* —screw connection; *3* — diaphragm; *4* — U-link; *5* — valve; *6* — valve strip lock; *7* — deflector; *8* — side guide; *9* — ring guide

(rosette). The diaphragm center hole is closed with a glass globe-valve resting on a valve washer which is held in place with a lock. The lock consists of three strips sealed to one another and to the washer and U-link with a quick solder. When the room temperature rises due to fire the solder melts and disjoins the strip lock into separate pieces. The glass globe-valve falls out thereby releasing a stream of water dissipated by the rosette deflector over an area of about 9 m^2.

The lock in a spray nozzle can also be made in the form of a glass cap filled with a liquid with a high coefficient of expansion and a low temperature of freezing. When the ambient temperature rises, the expanding liquid breaks the cap and opens the valve thereby releasing water for fire-fighting.

Long-term records on sprinkler performance indicate that 90% of all fires occurring in buildings had been successfully controlled by sprinkler installations before the public fire brigade came.

The general outlines of a sprinkler installation in an industrial-type building are shown in Fig. 98.

The sprinkler system uses water which is fed either from the public pressured water mains *1* or is pumped from an emergency tank *2*

with a pump *3* and fed in a pipe *4* connected to the system's mains line *5* that feeds an elevated water tank *6*. From the tank, the water passes through an alarm control device *7*, vertical feeders *8*, horizontal supply-pipes *9* and distributaries *10* to spray nozzles *11*. The elevated water tanks has a water-level indicator *12*.

In addition, the system is provided with a compressed air vessel *13* and an alarm *14* operated simultaneously with the automatic fire-fighting. Where the risks of fire are great use can also be made

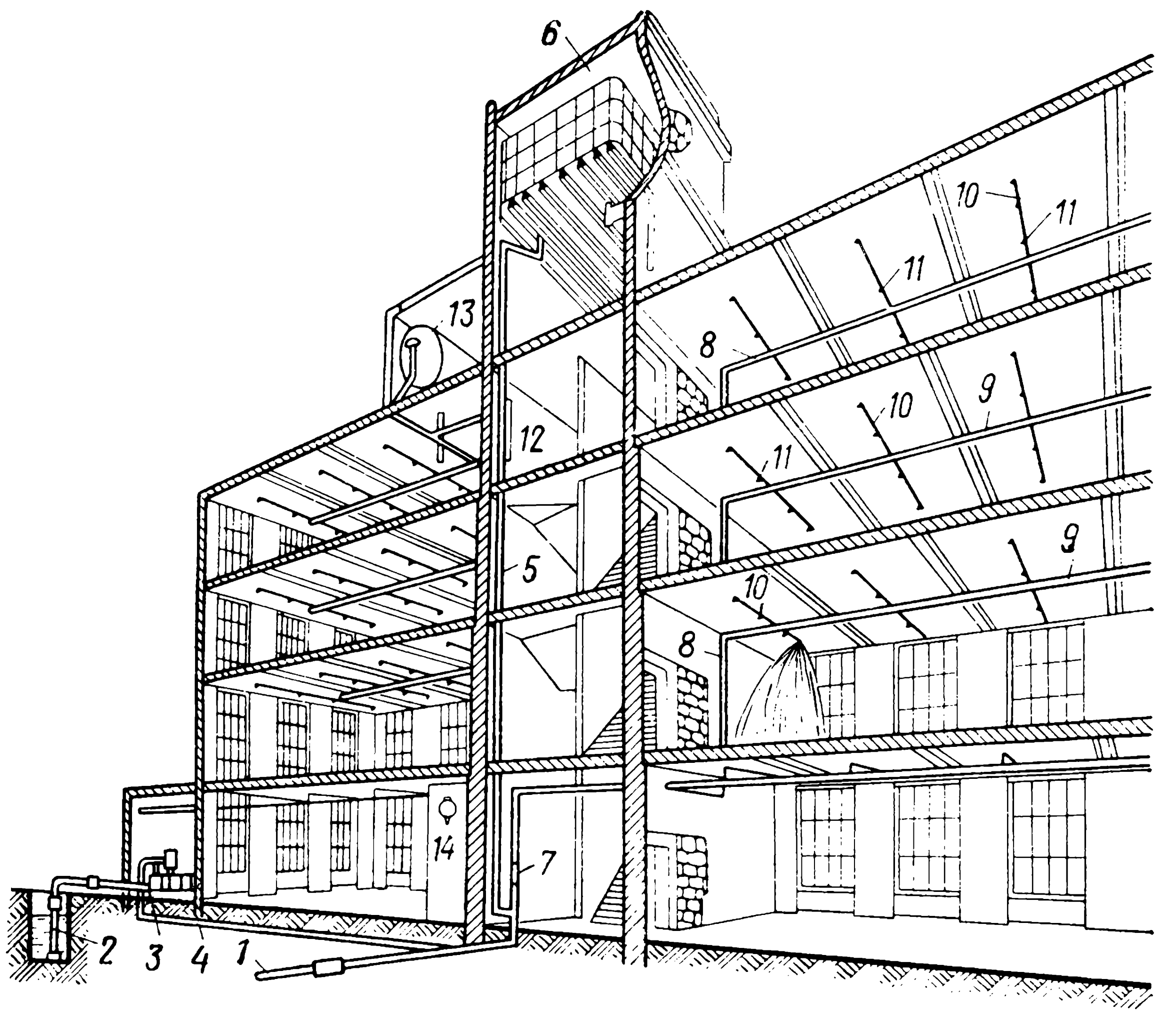

Fig. 98. General outlines of a sprinkler installation in an industrial-type building

of a fire-drenching system, which is intended for making water curtains to check or arrest fire, protect other buildings, and stop the spread of fire through the premise. The design and manner of operation of a fire-drencher is similar to that of the sprinkler. The difference is in the nozzle which is always open so when the system is automatically or hand-operated the water is released from all the nozzles at one and the same time. Water pressures and rates of flow in fire-drenchers are determined by a hydraulic analysis proceeding from the number of nozzles and their capacity. Normally, the discharge intensity in fire-drenchers is 0.1 l/(s m^2); it may be increased to 0.3 l/(s m^2) in buildings where the risks of fire are great.

CHAPTER 11

Safety Requirements for Industrial Equipment and Processes

Manufacturing industries employ so many machines, apparatus and tools that it is customary to divide machinery into a number of categories, namely prime movers, transmissions and working machines, all of which exhibit considerable variety. Irregard of the purpose, kind and type of machine, safety at work can be ensured only if the equipment design satisfies the safety requirements which are a matter of special accident-prevention design work based on the provisions of the Safety regulations for industrial establishments.

Good planning is as essential in safety as it is in production. If a new undertaking is to be built or an existing one readjusted there are many things affecting both safety and production that should be taken into account at the planning stage; these are site, facilities for handling and storing materials and equipment, floors, lighting, heating, ventilation, boilers, pressure vessels, electrical installations, maintenance and repair facilities, fire precautions, and collective and personal protection means and facilities. Principally, accident prevention or safety engineering should provide safety devices, precautions and protection means that are effective and convenient for the workers and meet the standards of industrial design aesthetics and ergonomics.

Accident prevention in manufacturing industries should include provision of machine-guards, brakes, automatic and distant control systems, interlockings and signalling (operating, warning and identification). Other protective measures include good house-keeping, personal protection equipment, colors, notices, signs and labels.

11.1. ACCIDENT PREVENTION: GENERAL PRINCIPLES

The general safety requirements are contained in the code of safety regulations for industrial establishments which lays down provisions for the safe design of industrial equipment and equipment parts. Standard safety precautions to be included in the design are issued

separately for each kind and type of industrial equipment and machine.

The construction principles of a machine or equipment ensuring safe and efficient production can be summarized as follows.

Industrial equipment or machines should be so designed that it will

— present no danger or cause discomfort or inconvenience to the worker during erection, use, maintenance, handling and storage;

— constitute no hazard when used singly or as part of a complex job or process;

— protect against unforeseen operational contingencies and not merely against normally expected hazards;

— cause no harm to the environment (the air, soils, water sources), be constructed from materials that are not dangerous or harmful by themselves;

— exclude contact with overheated or cooled surfaces;

— provide protection against electric shocks, and avoid accumulation of electric charges on equipment surfaces to dangerous limits;

— have built-in guards to provide positive protection and prevent all access to the danger zone during operation;

— exclude or minimize to safe limits the levels of ultrasound vibration, and radiation;

— exclude or minimize excessive releases of heat and moisture to permissible limits.

One major condition to be satisfied by equipment is its reliability, i.e. elimination of danger during service within the bounds established by operating instructions. The factors that may impair reliability of equipment are excess humidity, solar radiation, mechanical vibration, fluctuation of temperatures and pressures, corrosive substances, wind, icing, etc.

New materials that have not proved to be fire-resistant are not allowed for use in the manufacture of equipment. Such strict requirements for industrial equipment can be met only by choosing proper design, safe structural elements, reliable principle of action, mechanization, automation, use of remote control, etc. Operating instructions and maintenance manuals should indicate possible hazards and safety precautions to be taken during use, maintenance, handling and storing.

Component parts of equipment should be specially guarded against casual damage that may later cause accidents.

The construction of equipment and machines using gas-, vapor-, air-, or hydraulically-operated actuators should satisfy the rules of the safe construction of such systems. For the purposes of protection of machines and personnel safety industrial equipment is provided with additional means of protection, which can be general-purpose and specialized devices.

Special-purpose protective means include devices which protect from radiation, electric current, atmospheric electricity, etc. The safety requirements for the special-purpose protection appliances have been dealt with in the appropriate sections of the book.

General protective devices, such as guards, interlocks, brakes, etc., are concerned with the prevention of accidents due to unsafe behavior, incorrect work habits, or negligence.

11.2. MACHINE GUARDING

It has been mentioned earlier, machinery was and still is very important from the accident-prevention point of view. The need for safety precautions as regards machinery and equipment has always been a matter of major concern in accident prevention work. The practice of fitting guards to machines spreads gradually. The guards were often unsatisfactory for one reason or another, they were unreliable, they hampered the work, or they needed much attention. In fact the designers of guards tried mainly to comply with the law or eliminate the accident risk and gave little thought to the influence of the guard on production or to the nuisance it might represent for the worker. In the course of time requirements that a machine guard should satisfy were developed to the benefit of both safety and production. A suitable guard may not only provide adequate protection, but also improve the quality and quantity of the work done on the machine. In other words, a guard is not only a means of protection, but also a tool that facilitates work.

Many attempts have been made to make built-in safety for machines and other equipment a statutory obligation. The guarding of machines by the manufacturer is generally practicable in the case of guards for transmissions or guards at the points of operation where developments have been standardized.

All parts and points of machines and other equipment that constitute danger zones should be guarded. Only authorized persons are allowed to enter into these zones. Moving or rotating parts of machines are the examples of such zones (Fig. 99). The danger zone may occupy a permanent area or be continuously changing. In the first case, this may be the space between the die, hammer and the anvil, or geared rollers, pulleys in belt transmissions, etc. In the second, these are flying chips, or space in which a load is moved, etc.

We shall now consider some general requirements which a machine guard must satisfy. Guards should be so designed, constructed and used that they will

— provide positive protection; this means that should the guard cease to operate for any reason the machine will automatically stop or access to the danger zone be prevented;

— prevent all access to the danger zone during operation. Con-

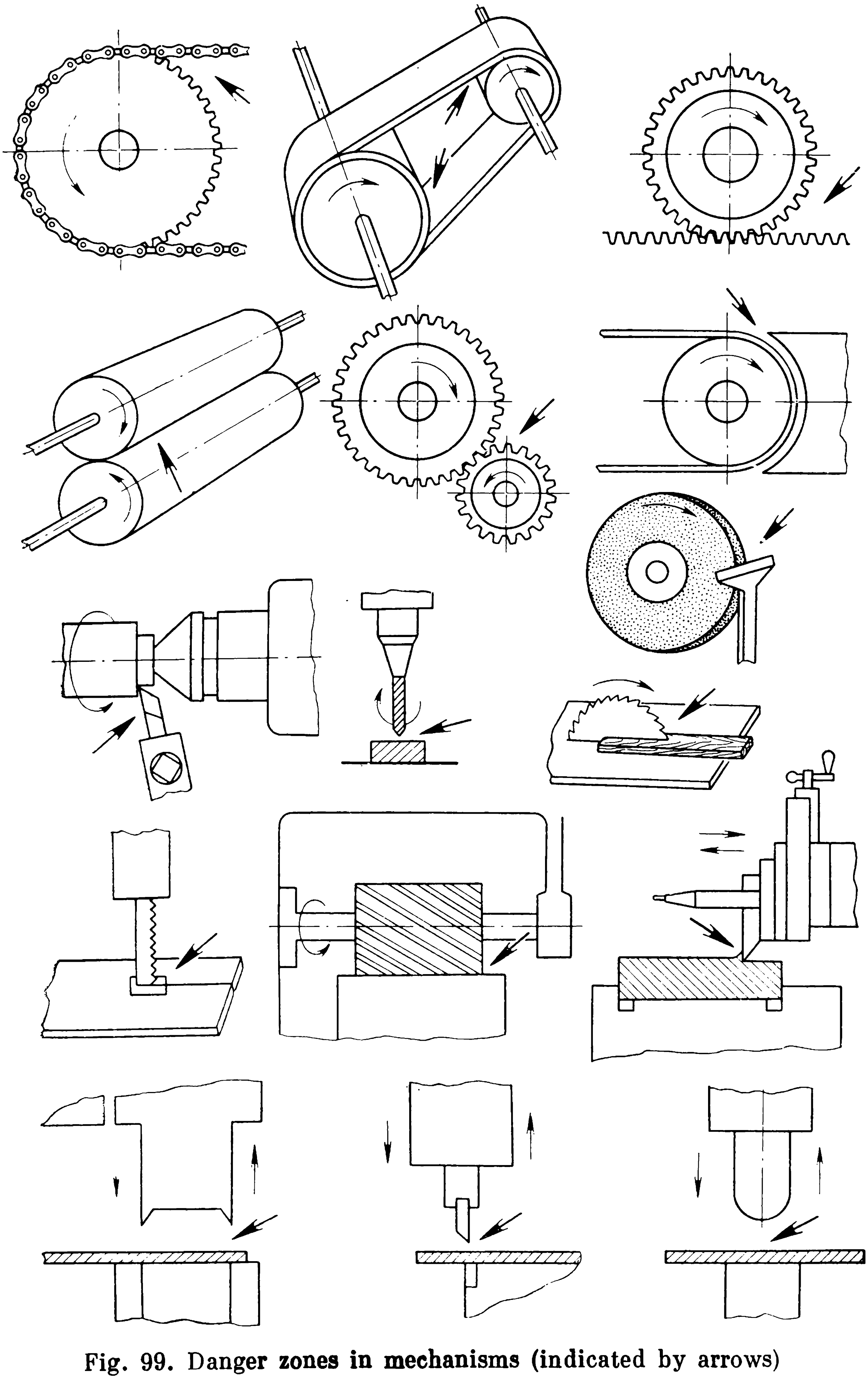

Fig. 99. Danger **zones in mechanisms** (indicated by arrows)

sequently, it is not sufficient for the guard to give a warning signal when there is a risk of any part of the body entering the danger zone, for instance by means of an alarm bell or a light signal; it should actually block all access to the danger zone;

— cause no discomfort or inconvenience to the operator. It is clear that the usefulness of guards which cause discomfort or inconvenience is lost. So the arrangement of guards should combine safety with ease of operation;

— not unnecessarily interfere with production. For this reason the use of guards that do interfere with production should be avoided if other systems exist and can give better protection. However, when it is impossible to find such a guard that does not interfere with production, safety should take precedence over production and imperfect protection should be preferred to an unprotected machine;

— operate automatically or with minimum effort. One special-type automatic guard is the electronic device working with photoelectric cells;

— be suitable for the job and the machine. Too often guards are constructed so that while giving real protection they are not suitable for the job, and are consequently not used;

— constitute a built-in feature. From construction point of view, much better results are obtained when a guard is part of the machine design than when it is added to the machine later;

— allow for machine oiling, inspection, adjustment and repair. Where these requirements are not observed, it is necessary to remove the guard for each of these operations; in practice, it is often not replaced with the result that the machine is unguarded when next used;

— withstand long use and normal wear and shock with minimum maintenance. It might seem unnecessary stress this point since all guards should satisfy these requirements. However, the construction of some guards leaves much to be desired perhaps because insufficient allowance is made for wear and tear (the fact that some guards may be opened and closed 800 times a day may be overlooked in the design);

— be durable, and fire- and corrosion-resistant. Special attention has to be paid to the choice of the material used. If the guard is not durable it has to be often replaced. If not replaced in time then the machine is unguarded. Fire-resistant materials are always to be recommended, and corrosion-resistant materials are necessary if the guard comes in contact with chemicals or used in very damp places;

— not constitute a hazard by itself. In particular, the guard should be free of splinters, sharp corners, rough edges or other sources of accidents;

— protect against unforeseen operational conditions, not only against normally expected hazards. Often, a machine is considered to be

adequately guarded if does not present any risk under normal working conditions. Experience has taught that this is insufficient to prevent accidents.

Of course, not all these requirements for guards can be satisfied but they should be as far as circumstances permit. It is clear that designing guards call for more research and experience from safety

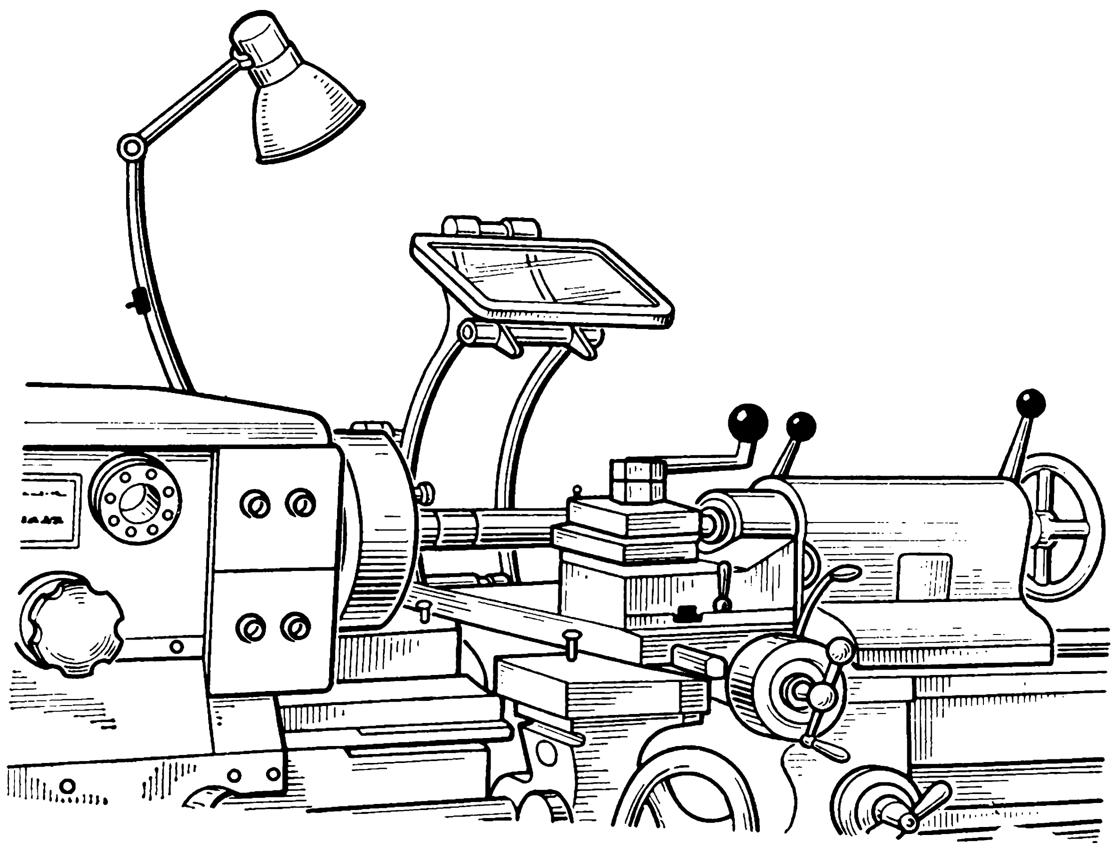

Fig. 100. A movable screen guard on a lathe

engineers. It is often required that movable screens be provided on metal-cutting machines to protect the operator. Such screens should be durable, effective, and convenient in use (Fig. 100).

If the work requires continuous observation over the process in the place of operation, the danger zone should be guarded with transparent materials which do not obstruct the worker's view of the job, are resistant to high temperatures and mechanical damage from flying chips and other solid particles. Where no standard guard can be installed or built-in, potential hazards should be indicated and the operator must be informed and instructed to use personal protection devices during the work. Machines that are used for working cast iron, brass and other dusty materials should, apart from the guards, be provided with specialized devices to evacuate dust during the operation.

11.3. OPERATING CONTROLS

Safe operation of a machine or equipment piece can be ensured only if it is equipped with adequate operating controls. The conditions to be satisfied by the operating controls of machines, machine-tools and other industrial-type equipment regardless of their power, size and purpose are as follows.

The controls should be so designed, constructed and used that they will:

— ensure a reliable starting and rapid shutdown;

— be easy and convenient in use;

— exclude erroneous or accidental starting of the machine or machine part, or a simultaneous starting of several units or mechanisms, which may cause serious trouble and accident;

— have individual power drives for the machine and feed mechanisms;

— have power engines interlocked electrically so that the feed mechanism is stopped as soon as the machine for some reason stops running.

The control should:

— be placed conveniently at hand not to interfere with operation;

— be suitable for the job, the operator, and the machine; operate automatically or with a minimum effort;

— be able to withstand long use and wear;

— cause no discomfort or trouble to the operator, or cause him to operate a wrong tool, or handle.

11.4. SAFE-GUARDS, INTERLOCKS, SIGNALS, AND COLORS

Protection of machines implies automatic tripping of mechanisms and machine units when the operating parameters deviate or go beyond the rated values and, hence, ensures the operator's safety. Protection means for each and every one machine and mechanism are considered separately. Safety catches and locks are indispensable in chucking appliances and retainers used to hold and secure workpieces, and particularly when such chucks are operated pneumatically, hydraulically or electrically. Special safe-guards and interlocks must be provided to prevent cases where workpieces may drop should the supply of air, liquid or electricity to the chucking device fail.

In chucking devices in which workpieces or blanks are secured mechanically, the operator's hand effort in securing the workpiece must be directed to himself to avoid hand injuries should the hand tool come off. When the blanks are to be secured or removed manually the construction of the machine clamping units (chucks, clamps, etc.) should ensure complete safety of such operations.

The design and construction of chucks and similar devices should make provisions for easy separation and removal of chips from the machine.

Handling and mounting of blanks on machines should not cause much trouble or inconvenience, or fatigue to the operator. The operator should always have at hand a trolley, boxes, hoisting mechanisms or loaders to assist him in lifting and positioning blanks, tools and other necessary appliances weighing more than 16 kg.

Hoisting mechanisms should be equipped with reliable fasteners or gripping devices for safe handling, holding in place and positioning blanks, articles and tools on the machine (Fig. 101).

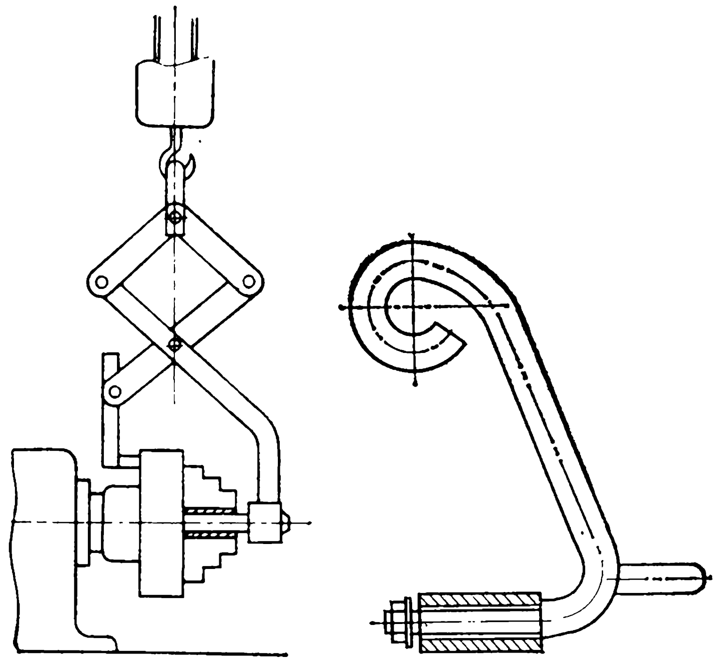

Fig. 101. A hoisting device for safe lifting, positioning and removal of chucks and workpieces

Interlocking is a popular safety precaution often taken to prevent injuries and can be applied to various types of machines and equipment.

Automatic interlocks, often called automatic safe-guards, serve as retainers fixing the working parts of apparatus or circuit elements in position, and are largely meant to:

prevent injuries due to accidents associated with operating a wrong control or with a disturbed sequence of operations or movements of mechanisms and mechanism parts;

immediately stop the machine as soon as the operator, or part of his body, occurs in a danger zone; or if the operating parameters of the machine or apparatus have, for some reason or other, altered;

prevent starting the machine or apparatus if its guards are not in place or open;

restrict movement of machine parts to preset limits, etc.

Normally interlocks are controlled mechanically or electrically.

One special type of automatic interlock is the electronic guard working with a photo-cell. In this system parallel light rays are projected in front of the danger zone of a machine. The interruption of the beam of rays stops the machine or prevents it from starting. Such systems have, as a rule, a high sensitivity, and the absence of the moving parts in front of the workers is also an advantage. But special care has to be taken to make sure that the beam is sufficiently wide and placed in such a way that all access to the danger zone

is prevented during operations. A schematic photo-relay protection for metal presses using rigid clutches is shown in Fig. 102.

Danger zone *1* of the press is guarded with light beam *2* projected from a lamp onto photo-cell *3*. In the same circuit with the photo-cell connected are also relay *4* and, through rectifier *5*, contacts *6* and electromagnet *7*. The interruption of the beam (the operator's hands are in the danger zone) actuates the photo-relay which sends a current through the coil of the electromagnet. This last draws

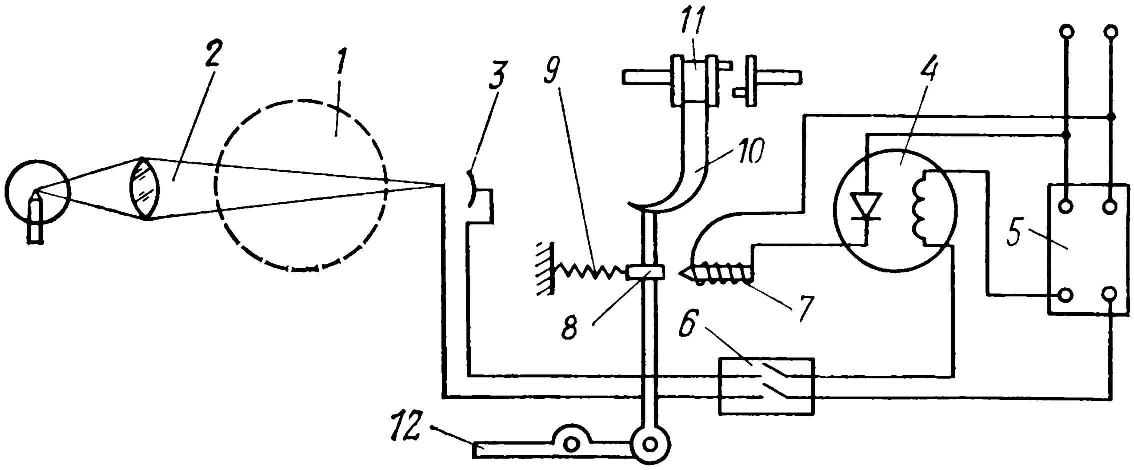

Fig. 102. Diagram of a photo-relay protection device in a rigid-clutch metal press

rod *8* retained with spring *9*, and puts the rod under lever *10* which operates clutch *11*. The rod is connected to control pedal *12*, which in this case is interlocked, so that the press cannot start.

Figure 103 shows a radioizotope protection scheme. Another example of an automatically operating guard is the hood for a tool-grinding machine which protects the worker from flying particles. The hood is connected to the starting mechanism in such a way that it cannot be opened when the machine is running, and when the hood is opened the machine cannot start.

In a similar way, opening the door to the cabin of a crane operator, or to a room housing high-voltage electric equipment automatically interrupts the power supply to the crane mechanisms and the equipment, respectively.

Various signals are used to indicate a coming event and to give warning before the event occurs. Distinction is made between the operating, warning and indicating signals, which are produced to be either heard (audible signals), or seen (video or visible signals).

Visible signals are usually provided in the form of light plates or panels, illuminated lamp indicators, light annunciators, light signs, illuminated information boards, flickering lights, mimic panels, etc.

Audible signals (frequency up to 2000 Hz) are sirens, whistles and gongs. They are recognizably identifiable in the surrounding noise sounds, and heard everywhere in the factory regardless of place, location, or posture that the job may require.

Video signals are perceived only when they are in the field of vision of the operator.

Two-color signals are normally used for controls to avoid undesirable consequences should a signal device fail. Depending on the operating conditions, one lamp (red or green) is always on, while the other is out; extinction of both indicates a failure of the device. To improve reliability, both lamps are connected in parallel so that one lamp remains operable should the other fail.

The operating signals are used to mark the completion of one stage and the onset of the next stage in a process, and also to coordinate the operations and efforts of the workers performing one job.

The warning signals are produced to inform the personnel about the coming danger or failure which might result in an accident, or accidents. Such signals are signs, placards, audible alarms and light signals operated by transducers immediately as they detect departures in the process or operation of machines from the normally rated parameters.

The indicating signals are intended for identification of danger zones in the equipment, machines or machine parts and production area sectors, and request that the personnel take special care and adequate safety precautions. They include notices and signs that may convey instructions, warnings or general information, remind of the danger in places with a fire risk, prohibit the opening of locked valves and switches controlling the equipment being repaired, etc.

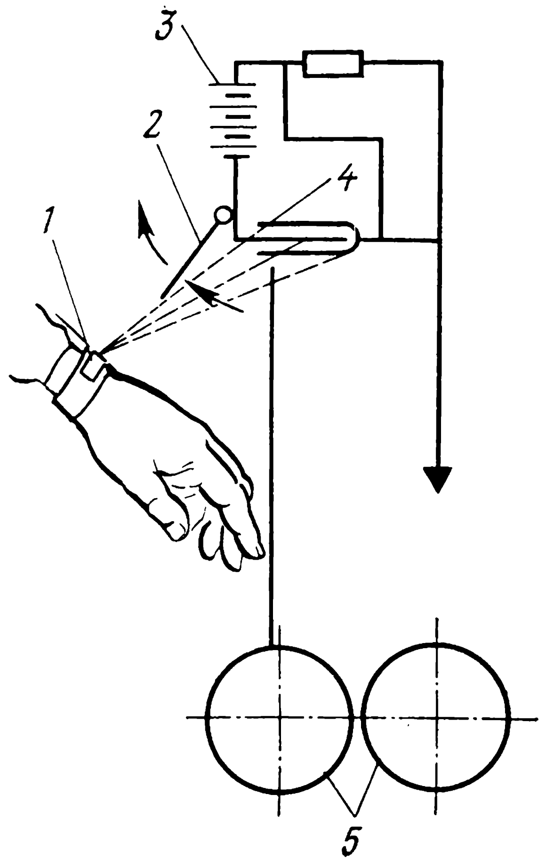

Fig. 103. Danger zone protected by an automatic guard sensitive to isotope radiation

1 — isotope safety band; *2* — screen; *3* — power source; *4* — radiation sensitive element; *5* — danger zone

Colors may be used for a variety of purposes in the interest of safety. A safety color code has been drawn up and generally adopted for use in industry:

Yellow (orange-yellow) color is used to indicate danger; for example to identify places normally covered by guards so that it is easy to see when the guard is missing, also to indicate that an apparatus is about to switch over to an automatic condition, or that a parameter (current, temperature, etc.) reaches its maximum. Warning signs, columns or other fixed objects near passages, obstructions of all kinds, etc., are often painted with inclined yellow and black lines in contrast with their surroundings.

Red color is used for stop signals, emergency stop devices and fire-fighting equipment, operating controls, tanks and cylinders to identify harmful contents, internal surfaces of guards to identify dangerous parts of equipment, etc.

Green color is meant for escape routes, first-aid stations, "go" traffic signals, and safety installations generally. The color is also used to indicate safe and normal conditions of mechanisms, circuits, physical parameters, such as pressure, temperature, etc.

Blue color is used for indicating signs and information notices when the above three colors are impracticable.

White color (achromatic) is used to confirm and indicate voltage (power input switch is closed), operating speed and direction, and other conditions that cannot be controlled automatically. Traffic lines, waste disposals may be marked with white lines.

11.5. ELECTRIC SAFETY

Many accidents are reported to occur because the metallic parts of industrial equipment, such as bed frames, casings, electric motor guards and control panels, are carrying mains voltage as a result of some internal defect or fault inside the apparatus. Accidents are also reported to have been caused by defects in sockets, plugs, or cables.

One essential measure to prevent accidents of this kind is the earthing or grounding of metallic parts of equipment which due to above causes are likely to be alive and carry voltages above 42 V. This can be done by connecting them to the grounding devices or to the neutral wire. The earthed points of the equipment should be easily identifiable and equipped with screws or claps for their fast connection to the grounding bar or neutral wire. It is essential that the earthed points, fixtures, such as screws and clamps, should have a coat of corrosion-resistant and current-conducting materials. It is inadmissible that the contact areas (between the screw head and the earthed point) carry paint, enamel or anything classed as insulation. Before making a connection it is necessary to make sure that the contact areas of the grounding device (conductor) and points of equipment are earthed and clean.

Table 36 may be found useful in choosing the size of screws and contact pads with which grounding conductors can be connected.

The nuts used in the fastening parts of grounding devices must be provided with spring or lock washers, and with other suitable elements which are meant to prevent slackening or loosening of connections. The use in the grounding devices of screws, pins and nuts designed as fasteners is inadmissible.

Table 36

Rated current, A	Screw thread minimum dia, mm	Contanct pad minimum dia, mm
Below 16	4	12
From 16 to 25	5	14
From 25 to 100	6	16
From 100 to 250	8	20
From 250 to 630	10	25
Above 630	12	28

The electric wiring in machines and equipment, regardless of voltages they use, should be carried out with wires whose insulation carries the following colors:

black (dark brown) for d.c. and a.c. power circuits;

red (orange, pink) for a.c. control circuits (alarm, measurement and local illumination);

blue (violet) for d.c. control circuits (alarm, measurement and local illumination);

green-yellow (green) for grounding circuits;

light-blue (grey, white) for circuits connected to the neutral wire and not intended for grounding.

It is admissible that wiring is sometimes carried out with monochromatic wires. In such cases, all wires should be identified at terminals with PVC (polyvinylchloride) tubes of appropriate colors.

11.6. CHIPS AND DUST DISPOSAL

As a result of all sorts of machining operations carried on in machine shops at manufacturing plants chips, pilings, cuttings usually accumulate in large quantities on and near the workplace. Metal chip can be continuous and discontinuous.

The discontinuous chip results from machining brittle metals (turning, milling, planing or drilling). Because of high cutting speeds discontinuous chips often fly over large distance from the point of cutting and can inflict serious injuries to the eyes, face and other exposed parts of the body. Accidents of this kind can be prevented by providing machine-tools with shields or screens to safeguard the operator, and with chip-removing devices to maintain the workplaces and the production area neat and clean.

Continuous chips form on turning or drilling viscous metal materials. They leave the cutting point in the form of an endless curl or shaving. The sharp edges and a complex trajectory of movement make it extremely dangerous and conducive to accidents. Also, because of high cutting speeds the chip temperature may reach 600-

700°C. Accidental contact with unprotected parts of the human body may result in severe burn injuries. The separation and handling of continuous chips are difficult, and therefore their disposal requires special safety measures.

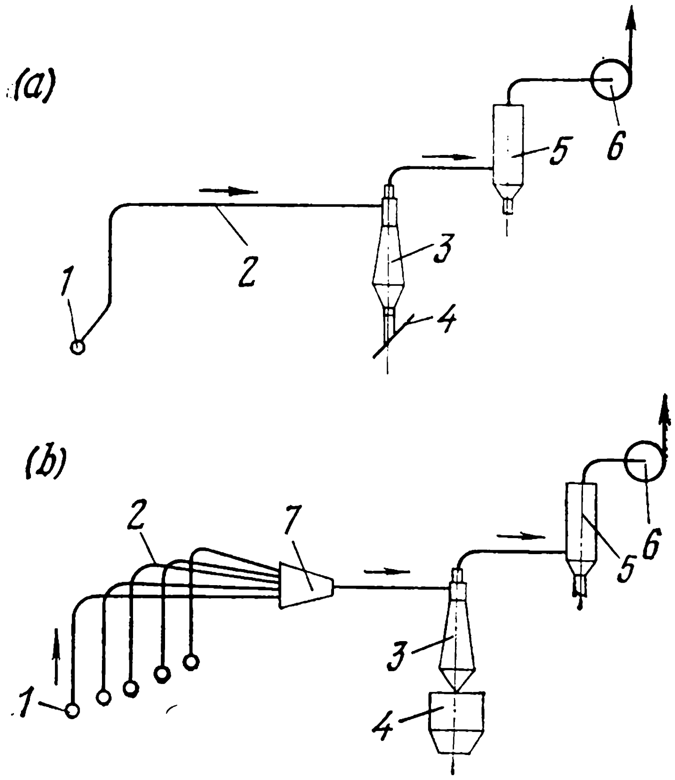

Fig. 104. Pneumatic systems for chip and dust removal

(a) single point system; (b) multi-point system; 1 — chip and dust catcher; 2 — conveying duct; 3 — chip separator (cyclon); 4 — chip bin; 5 — dust separator; 6 — induced draught fan; 7 — header

The hazards inherent in continuous chip formation can be eliminated or minimized by shaping the chip into a form safer and more convenient for handling and disposal. This can be achieved by using chip formers and chip breakers, or changing the geometry of the tool and the cutting speed.

The cutting conditions (speeds and depths) can be chosen so that the resulting section and shape of chip will facilitate chip crushing, separation and removal.

Chip breakers are used for crushing continuous chip to a suitable size. They can be made in the form of metal plates or straps welded or mounted on the cutting tool. Welded chip breakers are simple devices but not as durable as the cutters and therefore the tools have to be replaced too frequently. Straps or plates which are mounted on the cutter are more suitable as they can be easily replaced when worn out, and readjusted depending on the cutting conditions, the properties of the blank material, sharpness of the cutter.

The operator's safety and production convenience can be greatly improved by providing machine tools with automatic chip disposal systems (Fig. 104). Such systems usually include chip receivers, separators, collectors and chip conveying facilities.

Automatic and semi-automatic lathes which produce more than 30 kg of chip in one shift should be provided with conveyors for automatic machines chip disposal. It is advisable that all metal-cutting machines be equipped with built-in dust and chip catchers for continuous suction and removal of chip and dust particles from the operation zone (Fig. 105), in particular where articles from brittle materials are machined. The transport velocity of the air in the catcher branch-pipe and ducts should be not less than the free-fall speed of the air-suspended chip in a vertical pipe-line. The amount of air should be sufficient for handling dust and chip through the con-

veying ducts. The following quantities can be found useful as guidelines in determining air velocities, V, and the mass of air, Q, necessary for chip and dust transport:

Chip & dust material	V, m/s	Q, kg/kg chip
Brittle metals (grey cast iron, tin, brass, etc.)	not less than 35	not less than 1
Brittle non-metals (graphite, carbolite, fabric-based laminate, etc.)	not less than 25	not less than 2

The best way of preventing accidents is to eliminate the hazard by guarding the machine. At very high speeds of the working tools

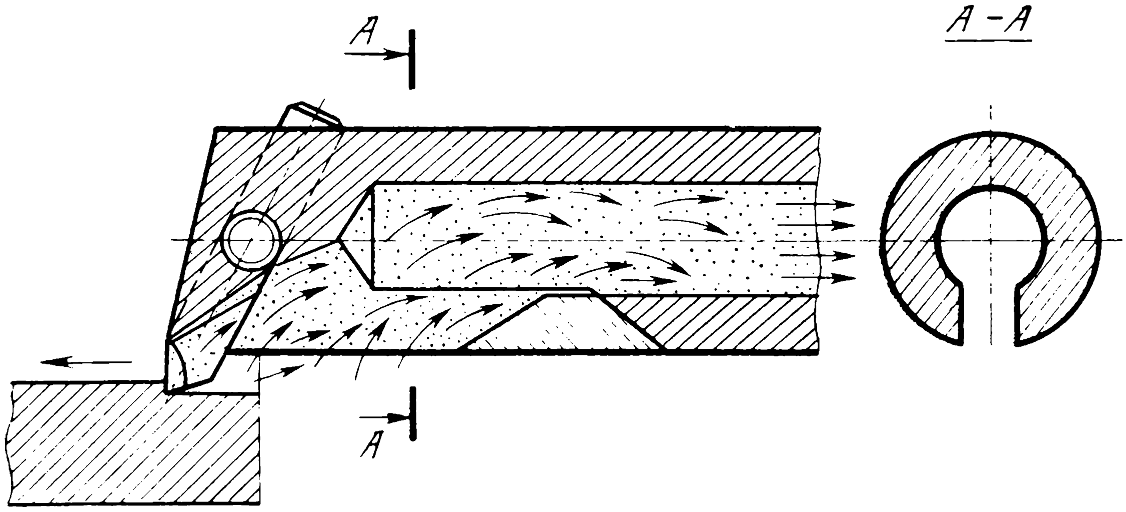

Fig. 105. A chip collecting cutter

exceeding 500 m/s, personal protective devices may prove ineffective. Screens should therefore be provided to prevent the eye and face injuries by chips flying from the point of cutting. The screens can be of different designs but of materials which do not obstruct the worker's view of the job, movable and easily adjustable, and should not interfere unnecessarily with production. But if it is impossible, it becomes necessary to protect the worker himself from flying chips by proving him with a mask, suitable goggles or shields.

There are various kinds of eye accident and different types of goggles have been found necessary depending on the work being done. For instance, goggles for workers engaged in chipping, cutting, grinding or similar operations in which flying fragments or chips heated to about 600-700°C could pierce the eye and cause burning injuries must have mechanically strong (shatter-proof) lenses. Protective shields have been found useful where it is necessary to protect not only the eyes but the face of the operator from high-velocity flying fragments. Such a shield can be a sheet of acrylic plastic with straps or strings for mounting on the head, and hinged so as to be raised or lowered on the face during the operation.

11.7. CONDITIONS TO BE SATISFIED BY SOME TYPES OF EQUIPMENT

The general safety requirements for industrial equipment lay down provisions for safety standards which specify safety measures and precautions to be taken for a particular type of equipment, machine or apparatus.

Pneumatic actuators have been widely used in mechanizing certain jobs and processes in manufacturing industries. Safety standards lay down the maximum limits on hand force to be applied on the controls of pneumatic actuators and similar devices. Thus, the maximum control force should not exceed 10 N for hand (wrist) control; 40 N where the forearm is involved; 150 N, for the arm, and 250 N, for two-hand control.

The posture of the operator controlling pneumatic actuators is very important. Consequently, the controls such as handles, knobs, handwheels, etc., should be located so that they will cause no discomfort to the operator, and be at his hand reach. Generally, for normal operating in a standing posture, the controls should be suitably elevated to a height of 1 000-1 600 mm; and in a sitting posture, to a height of 600-1 200 mm above the ground floor. All the controls must be provided with fixing devices, such as safety catches or locks to eliminate cases of self-actuation by force of gravity, vibration, or jolts. The controls of stop valves, shutters, brake valves and cocks should bear visible arrows indicating the correct direction for the "Open" and "Closed" positions.

The level of the noise produced by pneumatic actuators at the workplace should not exceed the limits for sound power levels ranging from 80 to 85 db (A).

Component elements of pneumatic actuators and similar devices must be tested for tightness under maximum operating pressure; and for strength, with a test pressure 1.5 times the rated pressure during 5 min. Exhaust air outlets should be provided so as to divert the foul air from the breathing zone. Concentrations of harmful substances in the exhaust air should not exceed the maximum safe limit values.

Abrasive tools are used for grinding, polishing, surface conditioning of metal articles, plastic and wooden products. They are also widely used for sharpening of cutters and fettling of castings.

Abrasive tools are available in the form of wheels, bars and segmental wheels which are manufactured from crushed abrasive materials bonded under pressure with phenolic resin plastic, ceramic or volcanite binders.

Abrasive materials can be natural (corundum, emery, diamond) and artificial (synthetic corundum, silicon-carbide abrasive, glass dust, etc.). The equipment in which abrasive tools are utilized are

all types of grinding machines with rigid and flexible shafts. The latter are intended for working large-sized workpieces of complicated profiles. Fig. 106 shows a tool-grinding machine with a protective screen and a dust evacuator.

The factors conducive to accidents are flying metal particles, fragments of abrasive material, disengagement and separation of the workpiece from the workbench or worktable, contact with the wheel if the blank is fed manually, breakage of the wheel from jolts, vibration, disbalance or overspeeding. Hazards and risks for the worker operating grinding machines also arise from the composite nature of the abrasive tool material (flaws, cracks, inhomogeneity, surf ce hardening due to misuse), high peripheral velocities which give rise to considerable centrifugal forces. In laying down the safe limits for operating speeds and peripheral velocities, the code of safe operation of abravise tools proceeds from the wheel diameter, kind of abrasive material, and the binder used. To avoid failure of wheels and serious accidents it may involve, care should be taken not to overspeed the grinder beyond the maximum safe limits prescribed by the operating instruction.

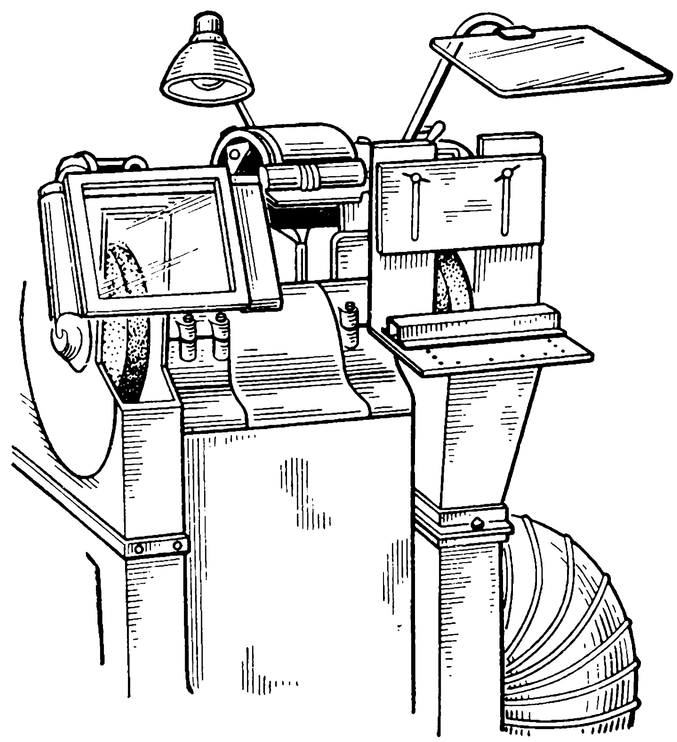

Fig. 106. A grinding machine wit a shield and a dust evacuator

Before being used in the machine, abrasive wheels are tested. Those made with a ceramic binder are first checked for absence or presence of faults and cracks. This can be done by clapping (sounding) the hanging wheel with a wooden hammer weighing about 200-300 g. Wheels are then center-mounted on test beds or rigs installed in special rooms, speed readings being taken from tachometers. Wheels with a 200 mm outer diameter and more (operating (rated) peripheral velocity, V_p, less than 100 m/s) are tested during 5 min at a speed, $V_t = 1.34$ times the peripheral velocity, or $V_t = 1.35V_p$; wheels 150 mm in diameter and more (the peripheral velocity, V_p, less than 40 m/s) are tested for 3 min at $V_t = 1.5\ V_p$.

Abrasive tools should be stored in heated, dry rooms equipped with racks and boxes in which wheels are kept vertically and separate from one another.

Guarding the abrasive tools on machines is mandatory. Guards are usually made from sheet steel in the form of casings dead faste-

ned to the machine bed or frame. The size and wall thickness of safe-guarding enclosures are standardized and depend on the abrasive material and wheel diameter; the side walls are made thinner than the front, impact-prone, wall.

Safe-guards or casings are made with an opening through which the blank or workpiece is brought in contact with the wheel tool (Fig. 107). The opening cutout angle (width of cutout) may be varied depending on the type of machine and the operating conditions

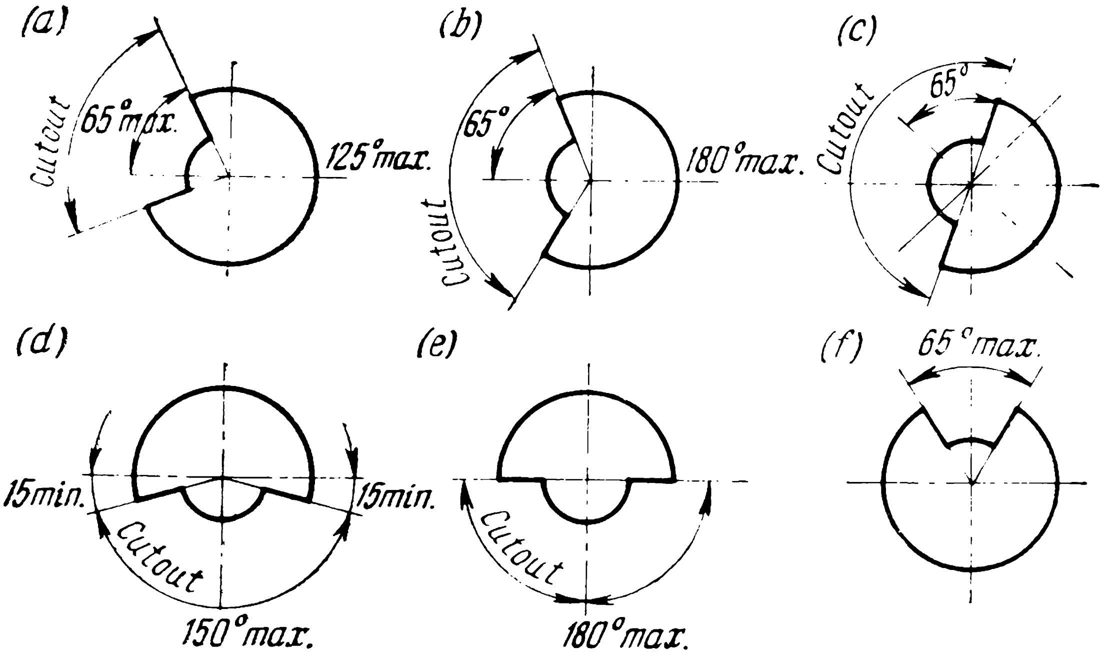

Fig. 107. Cutout angles (width) in abrasive wheel guards
(*a*) tool sharpener; (*b*) tool sharpener with a work point below the wheel center; (*c*) sphere and centerless grinder; (*d*) flat-surface grinder; (*e*) hand-operated swing-type grinder with a flexible shaft; (*f*) top-point grinder

for the abrasive tool. The opening should be sufficiently wide to ensure normal operation and minimum risk in case of wheel failure. The lower portion of such casings or guards is often made with a fixture to receive a branch-pipe inlet of an evacuating device.

Grinding machines in which the blank is fed manually should be provided with a steel subframe or underframe to support the blank; preferably the subframe should be made movable to make up for the wheel wear.

To minimize the risk of injuries, machines with flexible shafts are made to use special-type abrasive tools.

The fit tolerance for abrasive wheel is very important. Proper fit clearance for shaft-mounted wheels helps eliminate overstress due to heating that is conducive to crack formation, and wheel slip that may cause disbalance.

Secure attachment or fastening of the working tool is essential for the safe operation of machine. Normally, abrasive wheels are fixed in place with mounting flanges that may vary in design (Fig. 108). Elastic spacers or gaskets (rubber, leather, cardboard, etc.)

3 to 10.5 mm wide, depending on the wheel diameter, should by all means be used for wheel fastening with clamp-type flanges. The conditions to be satisfied in using flanges for wheel attachment are as follows. To avoid slipping of the wheel relative to flanges the force of friction between them should be greater than the cutting force, i.e.

$$fFr \geqslant pR$$

where f is the friction coefficient; F is the force with which flanges

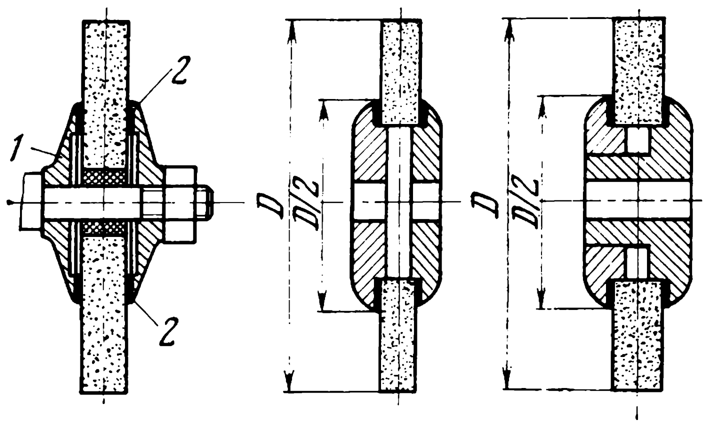

Fig. 108. Mounting flanges
1 — flange; *2* — elastic spacer

are compressed against the wheel, N; r is the radius of the flange contact ring, mm; p is the cutting force; J; and R is the wheel radius, mm.

From that expression

$$F \geqslant \frac{pR}{fr}$$

The force of flange pressure on the wheel (F) is determined by the force of nut pressure (compression) transferred through the threaded shaft section whose diameter is

$$d = \sqrt{\frac{F}{0.79\sigma_{ten}}}$$

where σ_{ten} is the ultimate permissible tension stress (30-40 MPa). The direction of the shaft thread should be opposite to that of the wheel rotation. In the case of a two-way wheel, the screw attachment should be secured with a screw stopper. Grindstone heads and wheels less than 200 mm in diameter are held in position by studs; and abrasive segmental wheels, by special-type chucking devices.

One common hazard inherent in abrasive tools is the formation of dust from fine particles and fragments from the materials, binders and workpieces. The formation of explosive dust can be minimized by substituting wet grinding for the dry process. With the wet process, care should be taken not to leave the wheel after working hours

in water as this may cause disbalance due to local charging of the wheel. Where wet grinding is impracticable, the workplace should be isolated from the rest of the production area, and an efficient exhaust ventilation installed.

Figure 109 shows schematically a local exhaust installed on a grinding machine for flat surface polishing. One feature that complicates the design is the specific distribution of dust in parallel with the work table. The rate of air suction (m^3/h) from the wheel,

$$L = qD$$

where D is the wheel diameter, mm; q is the volume of air removal, in m^3/h, per 1 mm of wheel wear; $q = 1.6\ m^3/h$ for sharpening and

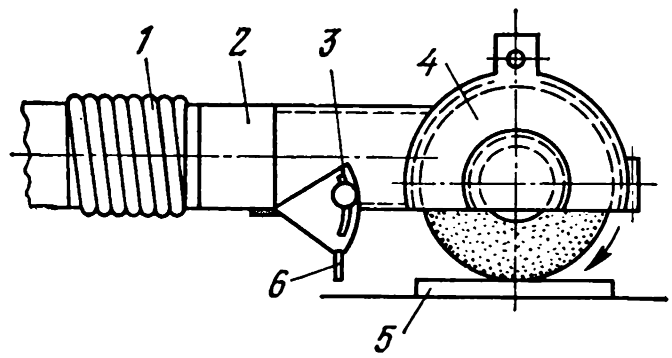

Fig. 109. A local exhaust installed in a grinding machine
1 — dust suction hose; 2 — inlet branch pipe; 3 — dust cup; 4 — guard; 5 — workpiece surface; 6 — dust damper

grinding wheels; $q = 2.4\ m^3/h$ for swing-type sharpening tools.

Among other safety precautions to be taken against eye injuries and for lung protection are local exhaust ventilation, use of goggles and suitable respirators.

Machine-tools are principal equipment in manufacturing plants. The general safety requirements for machine-tools are standardized, and certain additional safety precautions are indicated in the operating manuals and instructions, issued for each machine separately.

As regards machine-guarding, safe-guards protecting the zone of operation should also render protection to the operator against flying chips and splashes of lubricant-coolants. The construction of guards should not interfere with production, be suitable for the job and the machine, cause no inconvenience in the use, adjustment, and cleaning the point of cutting (Figs. 110 and 111). In all cases, the guards should be fixedly secured to the machine bed and exclude cases of spontaneous opening.

Automatic and semi-automatic machines should be provided with suitable interlocks which when the guard is open prevent the starting of machine. The external surfaces of the guards, machines, controls and other appliances and devices should be free of splinters, rough edges and other sources of injury.

The controls of machines designed for a sitting-posture operation should be located not lower than 500 mm and not higher than 1 400 mm above the floor or operating deck surface; and those designed for a standing-posture operation, 500 and 1 700 mm, respectively.

Foot-operated controls (pedals) should be not less than 220 × × 80 mm in size and knurled to prevent foot slippage. For convenience, pedal controls should be placed not higher than 100 mm above

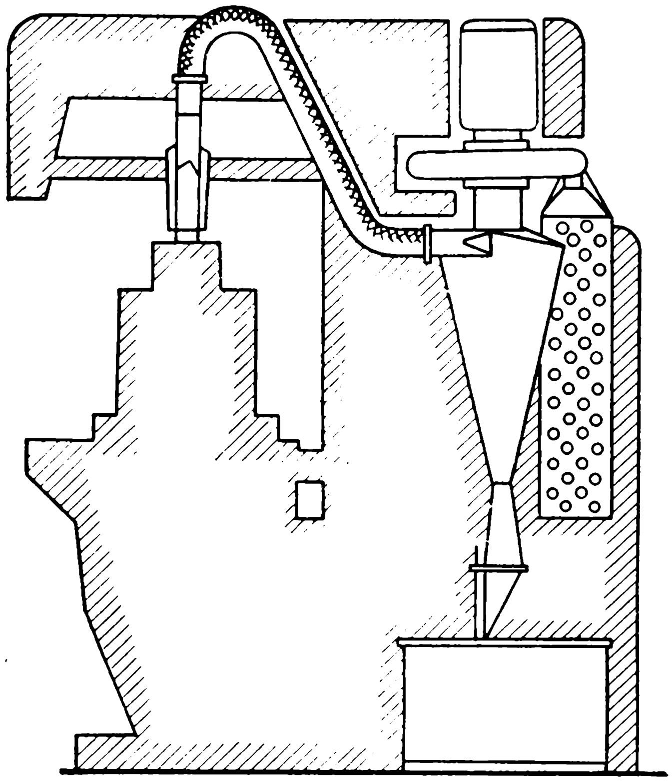

Fig. 110. Chip and dust removal from the zone of cutting in a milling machine.

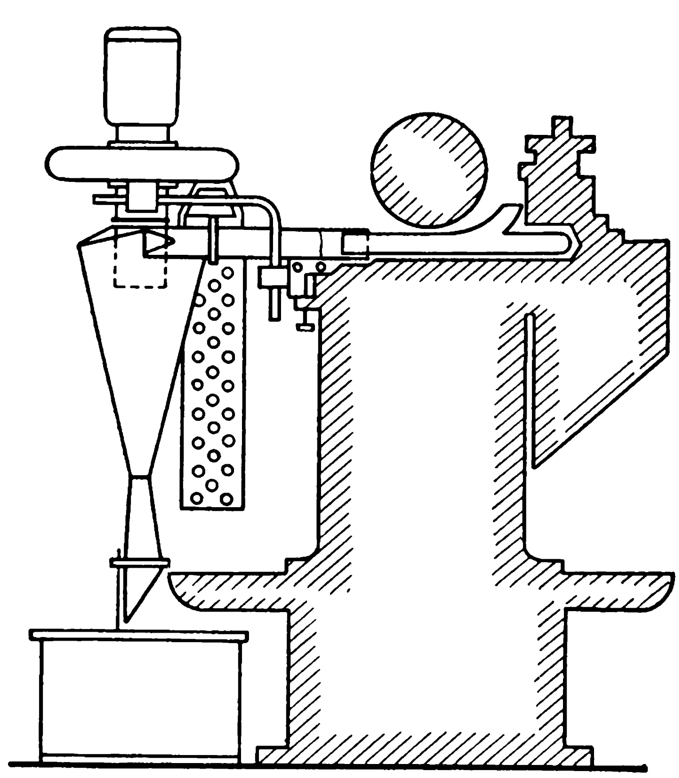

Fig. 111. Chip and dust removal from the zone of cutting in a turning lathe

the floor and have a displacement (operating) range from 45 to 70 mm. The pedal control force may vary from 25 to 40 N.

Hand control force should not exceed 40 N on knobs and handwheels, and 80 N on friction clutches for the initial and final efforts.

Control force should not exceed 160 N on the handles and handwheels to be opened or closed 5 times per shift, and 80 N on those to be operated 25 times per shift. The initial and final control effort on clamp levers and handles should not exceed 500 N. The starting manual effort in displacing the machine tailstock should not exceed 320 N. Where the tailstock requires a greater effort, the tailstock should be moved with a mechanical device specially provided for this purpose.

In turning and turret lathes, the free run of the spindle designed to accommodate up to 500 mm dia workpieces should not exceed 5 s, and 10 s in lathes for 630 mm dia workpieces, after the prime mover

has stopped. The free run should not exceed 3 s in drilling machines and 6 s in boring machines, and 5 s in milling machines.

On the completion of the working cycle, the tools and all the mechanically-linked elements should stop after the prime mover has been cut out within 5 s in gear honing, planing and shaping machines; within 30 s in gear-grinding machines using cone-shaped and profile abrasive tools; and within 40 s in gear-grinders using worm-type (helix) wheels.

Assembly units and equipment parts weighing more than 16 kg should be provided with bosses or lugs, holes, eye bolts, etc., for their safe hoisting and handling during erection, mounting and maintenance work.

A hoist or kind of lifting device must be available for each machine (and transfer machine) for handling heavy blanks (8 kg and more), tools and other necessary appliances (20 kg and more). A hoisting device should be designed so as to be able to hold a load in position even should the supply of electricity, air or oil fail. Workpieces weighing more than 250 kg are handled with the general-purpose lifting and loading equipment issued for the department.

Turning lathes must be guarded with screens. The screen thickness is nearly doubled for turning lathes operating at speeds beyond 5 m/s. Screens should have inspection windows from multi-layered transparent materials not thinner than 10 mm to provide adequate safety and good view of the job.

Automatic turning machines and turret lathes in which the workpiece is bars must be guarded with sound-proof materials along the entire length of the zone through which bars are fed into the machine.

Planing machines must be equipped with (limiting) end-switches and suitable brakes to prevent disengagement and sweep of the worktable.

Cutting-off machines and abrasive trimming machines should be designed and constructed so as to be easily attached to the dust disposal (exhaust) system.

The security of attachment of the guards in grinding machines should be high enough to hold the guards fast in place should the abrasive wheel fail. The zone of grinding which the operator has to face in high-speed grinding machines (60 m/s) should be completely screened and properly guarded. The guard with the inspection window should meet the requirements of high-speed cutting.

Band saw units should be completely guarded except for the point of operation the access to which should also be barred so as to make it physically impossible for the operator's hands to be caught in the band.

The danger zones in planing machines in which the operating stroke of the worktable or crosshead exceeds the length of the machine should be guarded. The safe-guard can be a fencing or any kind of a

barrier that blocks all access to the danger zone. High-speed planers must be equipped with brakes and end-switches to limit the stroke and prevent disengagement and comeoff of the worktable. Feed and reversing mechanisms, areas between the pedestal and the worktable should be properly guarded with shields.

When cutting sheet metal with inclined throat (guillotine) shears there is danger for the operator's hands to be caught between the cutting edges. Accidents of this kind can be prevented by adjusting the lower cutting edge in flush with the table and installing a guard which effectively bars access to the danger zone. The design of shears should exclude self-starting and spontaneous lowering of the upper cutter.

To prevent cut injuries, band and circular saws must be provided with mechanical devices that help feed or pass the workpiece through the cutting tool.

In drilling operations, workpieces should be fixedly secured in position with the help of bench or machine vices, or in jigs adequately anchored to the worktable. The chucks in drilling machines should ensure proper centering and fixation of the tool.

Transfer lines consist of individual transfer machines for metal working operations to be done in a particular succession. All the general safety requirements applicable to the individual machines equally apply to the transfer lines. Since the machines in the line are interconnected for automatic operation there are some specific conditions which transfer lines must satisfy in terms of safety. Normally a transfer line is controlled from a central control panel which gives choice between two control modes, namely the on-line (automatic) and off-line (adjustment) operations. The control system excludes spontaneous switching from one operating condition to the other. In the off-line condition, all transfer machines and mechanisms are controlled locally. It is very essential that the transfer line is designed and constructed so that in either of the control modes all the machines operate in a sequence prescribed by the production process, interlocks ensuring that the preset sequence of operations is not disturbed. All moving parts, mechanisms, working tools and workpieces should be safely guarded so as to block access to the danger zones when the transfer line runs automatically.

Chips from all the machines comprising a transfer line should be removed automatically by a wet or pneumatic process (Fig. 112) or mechanically with chain (flight) conveyors.

When in the on-line control mode, transfer, pick-up and release of the workpieces from one machine to another is controlled automatically with appropriate instrumentation.

Press-forging equipment. One of the basic requirements for press-forging machines is to prevent entry of the operator's hands into the danger zone, i.e. between the punch and the die. Sometimes, such ac-

cidents occur if the operator decides to adjust the blank to a correct position when the punch has already started, or due to an accidental starting of the machine by touching the pedal or push-button.

There are many ways to prevent accidents and avoid injuries during the operation of press-forging units. Interlocking has proved ef-

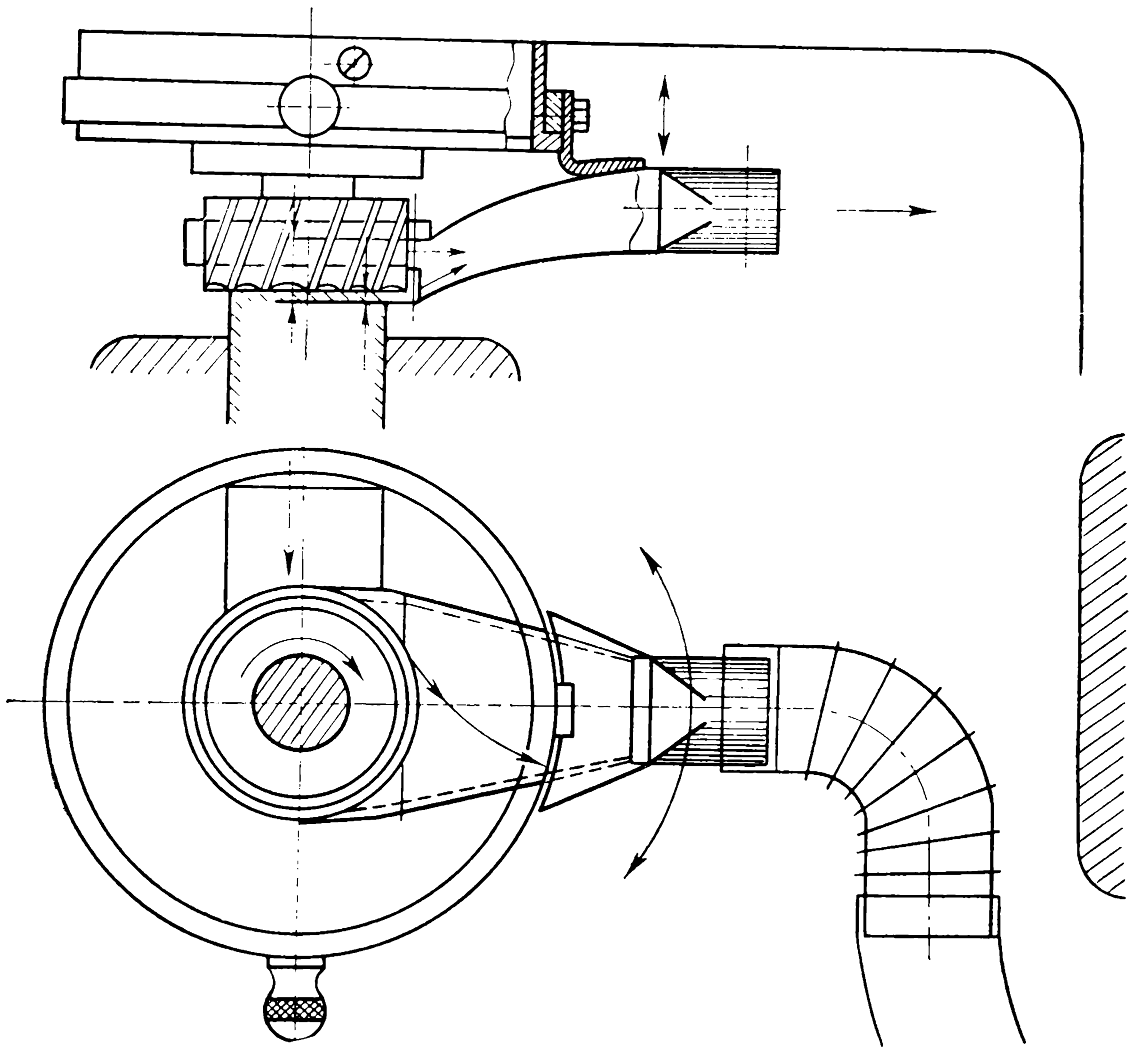

Fig. 112. Chip and dust pneumatic catcher

fective. Two-hand control in which two push-buttons or levers are interlocked so that the machine can be started only when the above two controls placed at a distance 300-600 mm one from another are switched simultaneously. Safety is thus achieved by making both hands of the operator busy with the controls of the machine since the interlock system excludes the possibility of starting the press with one hand.

Each subsequent starting requires that the two push-buttons or levers be released and operated again. Seizure of one of the two controls prevents starting. Accidental operation is prevented by the distant location and guarding of the controls. Self-release of the controls during the operating cycle causes immediate arrest, or return of the punch to the upper position. Other systems of interlocking per-

mit press machines to be operated with one hand and a pedal. Automatic guards are not necessary where workpieces or blanks have to be fed, held in place and removed manually outside the danger zone.

The pedal should be guarded from all sides except for the front to prevent accidental starting of the press machine.

The control force on hand-operated handles and levers should not exceed 40 N. The control force should not exceed 150 and 80 N on handwheels of power-driven machinery and rarely used hand-operated drives which are used 5-10 times and 25 times during the working hours, respectively. This however does not apply to hammers. Braking of the working tool should be mechanical, and the unbraking or release, mechanical, pneumatic or hydraulic.

Gas and flame welding, cutting and spraying equipment. The safety requirements for such machines and appliances are standardized and specified in accordance with the process for which a particular equipment piece is designed and used. Such equipment includes the machines and tools for oxygen and submerged-arc cutting, local heating and surface hardening, submerged gas-arc welding, brazing and soldering, flame spraying, plasma (jet) spraying or plating, and such appliances as gas-cutters, burners, gas-supply fittings, tanks, vessels and other types of receptacles for liquid fuel, gas reducing apparatus, valves in cylinders for oxygen and other flammable gases.

To provide comfort and ease of operation the controls (knobs and handwheels) in such machines, apparatus and tools should be suitably elevated (relative to the floor or operating deck) at 1 000-1 600 mm for the standing-posture operation, and at 600-1 200 mm, for the sitting-posture operation. The force necessary to apply to the controls depends on the elevation of controls, the hand used (left or right), and the direction (up- or downward). The control force for one-hand operation should not be more than 150 N on the levers and handles used less than 50 times; 250 N on those used more than 50 times during the working hours; 10-20 N on the regulating handwheels; 20-40 N on hand-operated closure controls; 40-80 N on those that require an effort from hand to elbow; it should not be more than 40 N on the controls for two-hand operation used more than 50 times during the working hours.

Cabinets of gas-supply stations should bear symbols usually used for labelling dangerous contents. The use of symbols for this purpose has the advantage that the labels can be understood by illiterate persons. However, it is desirable to use, or add to such a symbol, a text indicating the name of gas, description of the main risks; or a statement about the major precaution to be taken: "Acetylene. Highly Flammable"; "Fuel Gas, Flammable"; or "Oxygen. Avoid Contact with Oil", etc. Tanks for storing liquid fuel should be leak-proof at 0.49 MPa, and tested for leak-proofness at 0.98 MPa.

Hand tools. A large number of accidents are caused by hand tools,

The main causes of these accidents are the use of unsuitable tools, misuse of tools, poor maintenance and improper storage. The general recommendations for the prevention of such accidents and for the quality of materials for tools, laid down in the appropriate standards, can be summarized as follows:

hand tools for factory use should be made of materials of good quality and be appropriate for the work for which they are used.

Many accidents caused by breakage of tools or tool parts (such as handles) occur because the material used is of poor quality. Tools in general should be made of best-quality steel, and the handles for hammers, axes and similar tools of good quality dry hardwood (hickory, ash, maple or oak). Tools unsuitable for the job to be done such as hammers of incorrect shape or weight, and wrenches which are too long or too short, should not be used.

Hand tools must be used only for the specific purpose for which they were designed.

The use of hand tools for the purposes other than those for which they are designed (for instance, using a knife as a screw-driver, or a spanner as a hammer) is dangerous because the tools may break, splinter or come off, and so cause an accident. The remedy is careful planning of the composition of sets of tools and tool kits for different workers. Every worker who knows his job will certainly use the right tool.

Wooden handles of hand tools should be of best-quality straight-grained material, of suitable shape and size and smooth, without splinters or sharp edges.

A good-quality springly hardwood such as hickory, ash, maple or oak should be used for handles. The length of the handle will obviously depend on the type of tool for which it is used. The handle should be shaped to fit the opening of the head of the hammer. Special care should be taken to fix the head of the hammer at right angles to the handle, otherwise the joint is dangerously weakened and when the hammer is used the head may fly up and injure somebody.

Where there is a risk of an explosive atmosphere being ignited by sparks, the hand tools used should be of a non-sparking type. In such cases the tool to be used should be of wood, hard rubber, copper, beryllium alloy or some other alloy which do not produce sparks when hit.

Hammers, sledges, cold chisels, cutters, punches and other similar shock tools should be made of carefully selected steel, hard enough to withstand blows without mushrooming extensively but not so hard as to chip or break.

The hardness of steel shock hand-tools influences safety to a large extent. Excessively soft steel will soon mushroom at the point of impact and if the tool is not ground in time small particles will be loosened by impact and fly off endangering persons in the neighborhood,

and in particular their eyes. Excessively hard steel, too, may splinter on impact; such splinters may sometimes penetrate deep into the eye, and cause blindness. To eliminate these risks steel used for tools should be neither too hard, nor too soft; the limits are often laid down.

Hand shock tools should be ground to a suitable radius on the edge as soon as they begin to mushroom or crack, and tempered, dressed and repaired by qualified persons.

Workers should be properly trained and instructed in the safe use of their hand tools.

Fig. 113. A workbench guarded with a screen

The standard safety regulations also contain recommendations for storage, issuing, inspection and maintenance of hand tools. Maintenance and repair personnel must be provided with special tool kits or portable tool boxes of a size sufficient to hold all the hand tools needed for their work, and so constructed that they can easily and safely be hoisted onto platforms or other elevated workplaces. Where necessary special handtrucks should be available for handling heavy tools needed in repair and maintenance work. All repairmen must be provided with goggles and other personal protective devices; their workbenches should be guarded or shielded, often with suitable screens (Fig. 113).

Portable ladders, steps and tresles. Portable ladders are used to give access to scaffolds, platforms, operating decks and other places in buildings where workers have to go for maintenance and repair work, and for many other purposes.

The design of a ladder depends on the use to be made of it. The ladders to be used in erection sites have to be more rigid than ladders for maintenance and repair. Aluminium ladders have advantages over wooden ones for they are extremely light. However, it is dangerous to use metal ladders in the neighborhood of uninsulated electric wires because all metals are good electric conductors.

The construction of ladders for the factory use has been standardized, and different types of ladders tested.

Generally, ladders should have the rungs placed at an interval of not less than 15 and not more than 25 cm; ladders for general purposes usually have the rungs placed at about 25 cm. Ladders (portable and step-ladders) should not stand on loose bricks or other loose packing but have a level and firm footing. A firm footing is one of the most

important safety precautions to be taken with ladders. The ladder should be securely fixed so that it cannot move from its top or bottom points of rest. To acquire a firm footing, ladders are usually provided with hooks at the top and pointed bases at the bottom. If it cannot be secured at the top the ladder should be securely fastened at the base. The uprights usually made of good

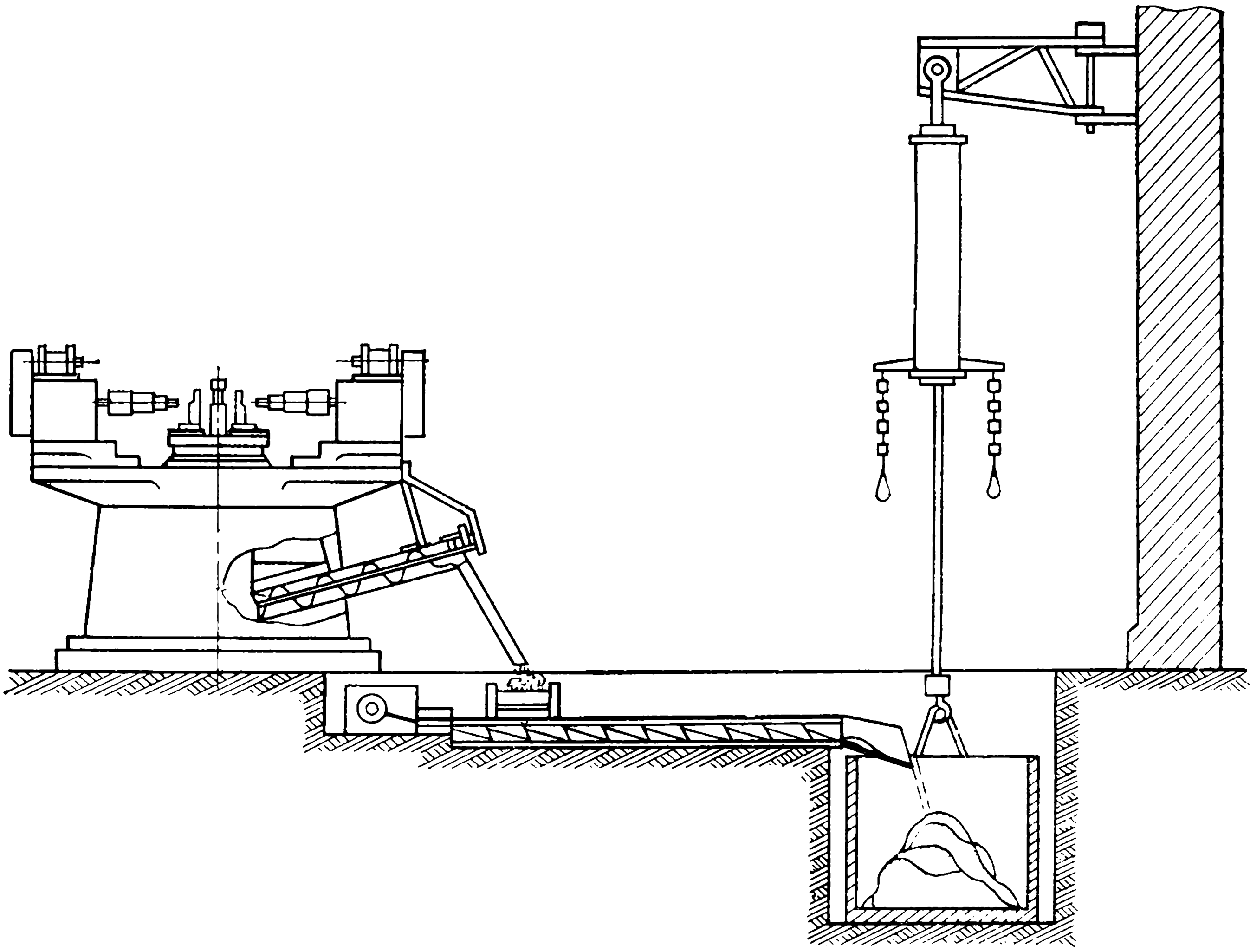

Fig. 114. Mechanical chip removal to a place of disposal

quality wood are not parallel but converge slightly toward the top. Rungs are usually mortised in slots in the uprights and kept in place by glue or wooden safety pins.

Because roofers' and painters' ladders are often of a very light construction and are insufficiently rigid for general use, such ladders should not be used by workmen in other trades. Sometimes, portable ladders and wooden step-ladders should instead of pointed bases be equipped with non-slip bases, particularly when used on concrete or asphalt floors. Special attention should be given to the effect of wear on non-slip bases. Many types are satisfactory when new but become unsuitable after being used for some time. Regular inspection is therefore necessary. It will be noted however that most non-slip bases are useless when the floor is wet or covered with oil.

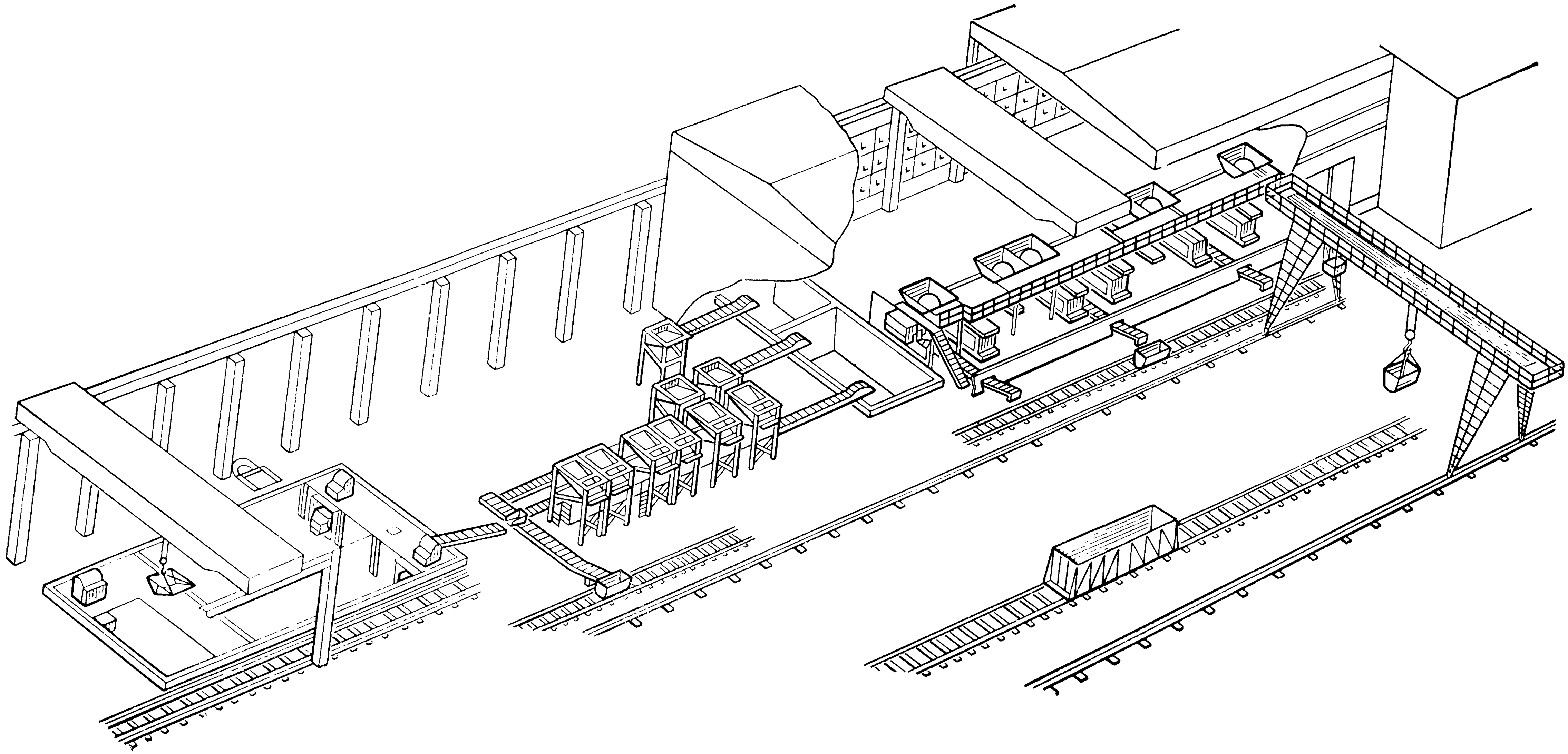

Fig. 115. Metal chip briquetting plant

Portable and extension step-ladders 3 m long and more should have at least two metal couplings bolts under the rungs, and be equipped with a safety device to prevent self-extension. When fully extended, the length of such a ladder should not exceed 5 m.

Gangways, footpaths or catwalks should be made rigid and fixedly secured to avoid sagging or permanent set. The sag of a deck or a floor boarding should not be more than 20 mm at the maximum rated load. Flying bridges longer than 3 m should be not less than 0.6 m wide, have intermediate supports placed at not more than 2 m, and

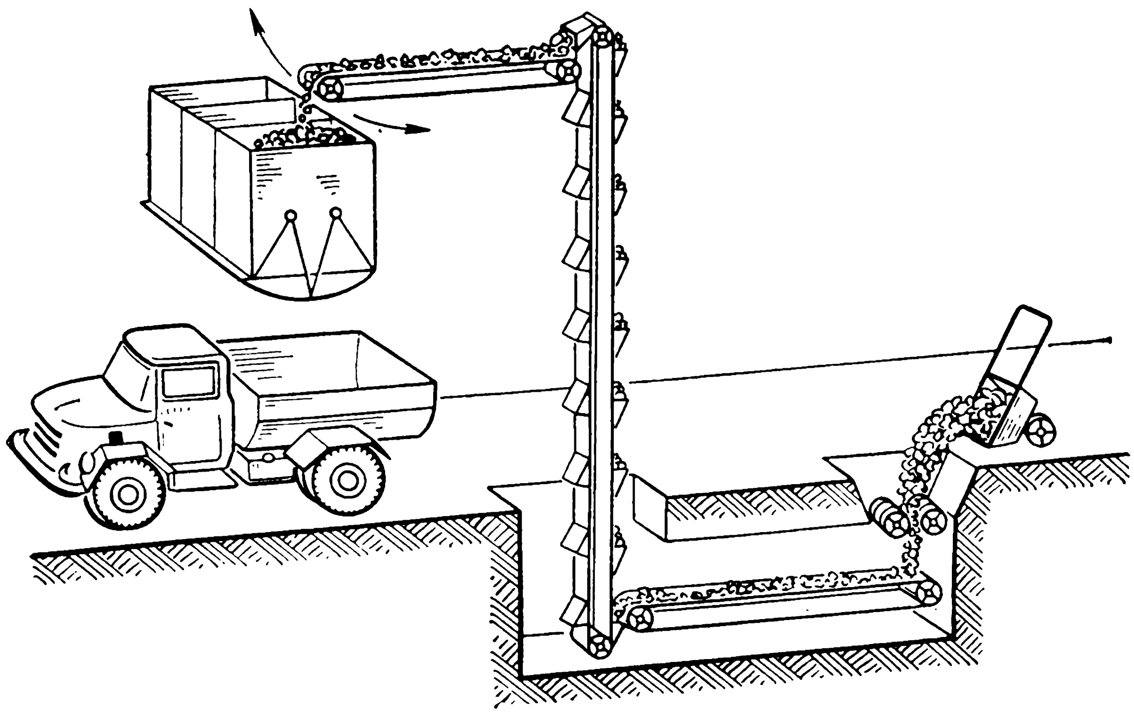

Fig. 116. Shreading and loading of chip for salvaging

should ensure a clearance of at least 1.8 m. Bridges, footpaths and elevated decks should have handrails about 1 m high and ledges or rims on both sides rising to about 15 cm above the floor level.

Waste disposal. Utilizable and non-utilizable wastes (scrap, recoverable refuse, etc.) in an industrial undertaking should be collected and prepared for salvaging and reclamation. Waste disposal facilities usually include subsurface conveyors or scrap containers which take off all scrap and refuse from the production areas to specialized disposal places (Fig. 114) for preparation, i.e. shredding, briquetting (Fig. 115), cleaning, and disposal.

In some plants metal chip, scrap and junk are collected and hauled to specialized salvaging plants (Fig. 116).

Where processes or machine operations and procedures require large quantities of lubricants it is economically feasible that the lubricating oils are reclaimed right for further use. Reclamation plants are normally installed near storage facilities for lubricant materials.

Other recoverable refuse such as cleaning cloth, oily wastes are usually collected and cleaned in centrifugal units. Where necessary cleaning cloth can be washed with detergents and dried by centrifuging.

11.8. HOISTING, LOADING AND HANDLING MECHANISMS

It is common practice in design and strength analysis that all the principal parts, particularly ropes in hoisting and handling mechanisms are loaded conservatively.

Ropes and chains are essential parts of hoisting equipment. The methods of securing the ends of wire ropes and their tightening are usually given in the operating and maintenance instructions issued for a particular mechanism. The strength of stay ropes, track cables, haulage and drag wire ropes, hoisting and pulling wire ropes can be checked using the expression

$$P/S \geqslant k$$

where k is the safety (assurance) factor; P is the breaking load, N; S is the maximum stress anticipated in rope strand (without allowance for dynamic load), N.

The stress of wire ropes depends on the number of strands and the angle formed by the pulling rope (Fig. 117). The minimum values for the safety factor for certain types of wire ropes are given in Table 37.

Table 37

Type of rope	Type of drive	Operating duty	Safety factor, k
Hoisting	Hand-operated	—	4.5
Boom runner	Power-driven	Light	5.0
		Medium	5.5
		Heavy	5.5
		Very heavy	6.0
Tackle block	—	—	6.0
Winch for hoisting people	—	—	9.0

Calculations can be carried out using the formula

$$S = Q/(\cos \alpha\, n) = cQ/n$$

where S is the stress in each strand of wire rope, N; Q is the mass of load, kg; n is the number of rope strands; c is coefficient that depends on the angle α formed by the rope ($c = 1.0$ at $\alpha = 0$; $c = 1.15$ at $\alpha = 30°$; $c = 1.42$ at $\alpha = 45°$; $c = 2.0$ at $\alpha = 60°$).

The safety factor for pulling ropes using hooks, rings or shackle (clevis) should not be less than 6. Wire ropes having 10% broken wires per pitch of a strand should not be used; splicing is inadmissible. Generally, wire ropes used for hoisting and handling equipment should have an effective breaking strength five times the greatest anticipated stress in the rope, and four times in the case of hand-operated devices.

The safety factor for welded chains can vary from 3 to 9 depending on the type and purpose and the kind of drive used. When chains

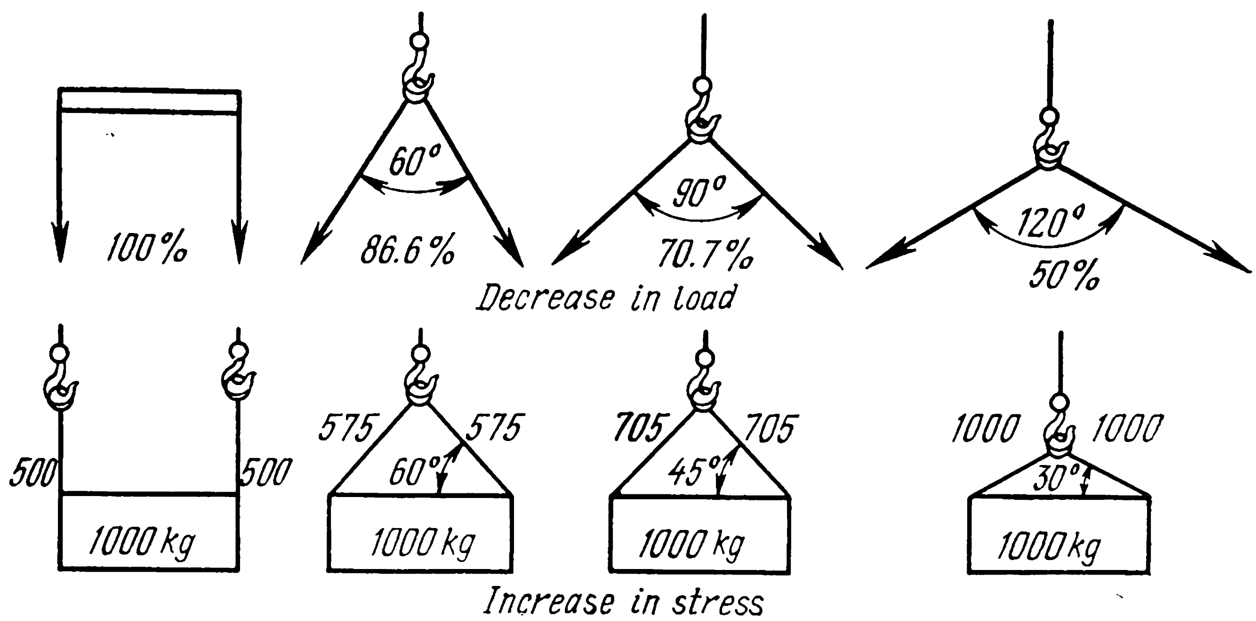

Fig. 117. Stress in rope and safe loads depending on the angle formed by pulling ropes

show 10% wear relative to their original diameter they should be withdrawn from use.

The diameter of the sheaves of pulley blocks measured at the outer circumference of the sheave should be $D \geqslant d\ (e - 1)$ times the circumference of the rope to be used, where d is the rope diameter, mm; e is the coefficient which can take any value from 16 to 30 depending on the type of hoisting mechanism and its operating duty.

Chains, wire ropes and fibre ropes should be thoroughly examined at specified intervals. The number of broken wires per pitch of a strand served as a basis for discarding ropes and withdrawing them from use. The pitch or lay of a strand is the distance along the rope outer circumference in which all strands of the wire rope section are laid. The conditions which serve as the basis for the rejection of ropes as inadequate for further use are given in Table 38.

The above given figures are twice less for hoisting wire ropes used in hoisting mechanisms intended for lifting people and handling dangerous loads, such as molten metal, acids, explosive, flammable or toxic substances.

Table 38

Safety factor	Number of wires in ropes having one organic core							
	6×19=114	6×37=222	6×61=366		18×19=342			
	Number of broken wires per strand pitch of rope laid with a twist							
	cross	side	cross	side	cross	sid	cross	side
Up to 6	12	6	22	11	36	18	36	18
6-7	14	7	26	13	38	19	38	19
Above 7	16	8	30	15	40	20	40	20

For wire ropes showing substantial deterioration due to wear or corrosion the number of broken wires (Table 38) by which they can be rejected as inadequate for use has to be reduced as recommended in Table 39.

Table 39

Reduction in rope diameter, %, from wear and corrosion	Number of broken wires per pitch of strand in percent of that in Table 39
10	85
15	75
20	70
25	60
30 and more	50

Wire ropes which have lost 40% of their original diameter due to wear or corrosion, or have one strand completely broken should be withdrawn from use.

Hoisting chain drums or pulley should have a diameter of not less than 20 times the chain size in hand-driven mechanisms, and 30 times of the chain size in power-driven machines. Where sprocket is used the round- and leaf-link chains should be constantly engaged with at least two teeth of the sprocket.

Power and hand-driven hoisting equipment should be provided with effective braking devices for controlling the lowering or raising of loads, and of the boom reach. The braking devices should ensure a braking moment with a certain assurance or safety factor. The braking safety factor is the ratio of the braking moment to the static moment created on the brake shaft by the maximum safe working load. The magnitude of the safety factor (Table 40) depends on the operating duty and the type of the drive mechanisms.

Table 40

Operating duty and type of drive	Safety factor
Hand-, and power-driven light-duty mechanisms	1.5
Power-driven medium-duty mechanisms	1.75
Power-driven heavy-duty mechanisms	2.0

The speed of the ground-operated travelling cranes should not exceed 50 m/min, and that of the crane trolley, 30 m/min. Where an erection work requires high degree of accuracy in lifting, carrying and lowering loads, the operating speed should be restricted to safe limits.

Power-driven loading machines travelling at speeds higher than 30 m/min should be provided with hand or automatically-operated brakes. The brakes are mandatory for ground track-controlled cranes regardless of their travelling speed.

All parts of hoisting and load handling equipment should be of sound material, good construction and adequate strength; kept in good maintenance and order, and ready for use; fitted with devices to prevent over-running; and provided with safety devices to ensure that in the case of power failure or a break in the power supply, the load will be held in position.

The sheaves and housings of pulley blocks should be constructed so as to prevent catching of rope between the sheave and the sides of the block, and distortion of the rope due to improper fit in the sheave.

Hand-operated hoist mechanisms should be provided with:

— ratchet wheels on the drum shafts and locking pawls, or self-locking worm gears to prevent reversing when a load is being hoisted; and

— effective braking devices for controlling the lowering of loads.

Crank handles for hand-operated winches should be either:

— constructed so that they do not turn while the load is being lowered by means of a brake; or

— removed before the load is lowered.

Detachable crank handles for hand-operated winches should be secured against accidental removal.

Power jacks and other hoisting mechanisms should be provided with safety handles which, connected to the ratchet and pawl mechanism and the braking device, ensure automatic arrest and holding in position of the load, should the operator lose hold of the handle.

Where roller conveyors (beds and tables) are used for handling loads the essential safety precautions include the guides and guards on

the open side of the conveyor particularly at points of turning to prevent falling, collision and overturning of loads.

Screen guards should be provided for suspended flight (chain) conveyors to prevent accidents due to falling of loads; and arrestors or load catchers for inclined conveyors to prevent reversing of loads in the case of chain failures.

Electric monorail or electric wire rope hoists and similar electric loading devices should be provided with end (limit) switches to prevent over-running of the load, impact against the block body and rupture of rope. End switches and lift stops should be installed so as to arrest the load at a distance of 200 mm to the upper reach point.

Travelling cranes should have end switches too and end stops to absorb the shock and prevent over-running of the crane, or crane trolley.

All hoist mechanisms must be equipped with load-limiting devices (Fig. 118) to eliminate cases of overloading and accidents this may involve. Besides, the safe operating load should be incised, stamped or marked in a conspicuous place and in a legible and durable manner on all hoisting and handling mechanisms before they are brought to use.

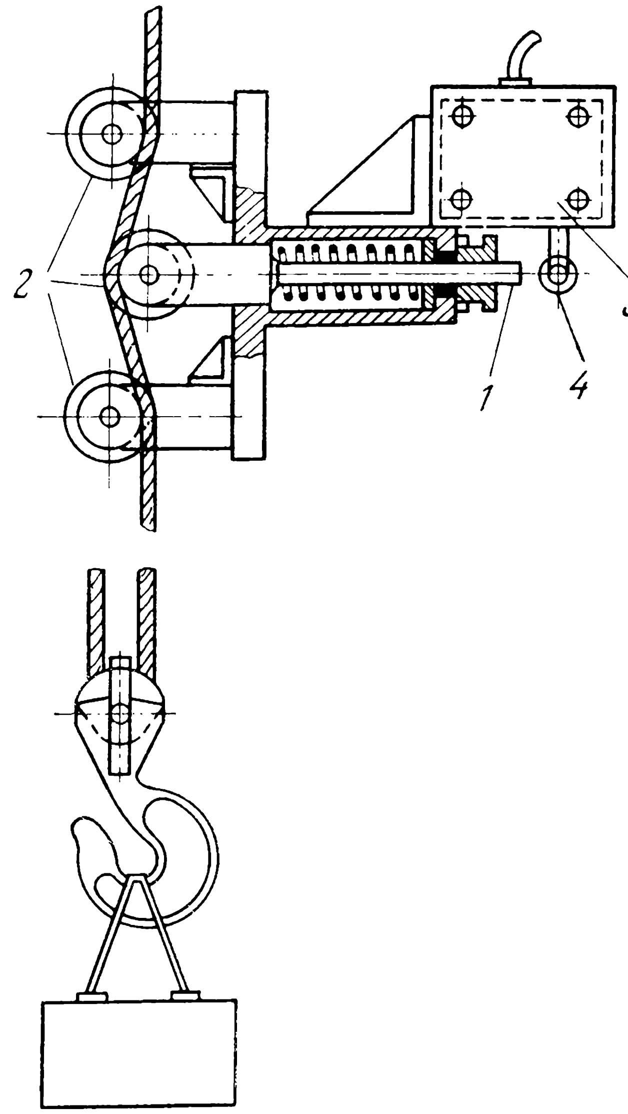

Fig. 118. A load limiter
1 — rod; 2 — rollers; 3 — switch; 4 — switch lever

The fitting of the operator's cabin should not adversely affect:

— access to and freedom of movement normally enjoyed by the operator when he is in his normal operating position;

— access to the crane controls;

— environmental comfort (Fig. 119), noise level and visibility.

The cabin should be fitted in such a manner as to prevent excessive heat, draught, dust and fumes reaching the operator, and to exclude electric shock accidents in the case of internal or external electric faults.

Elevators or lifts for carrying people or handling loads should be provided with safety devices, such as interlocks which prevent the starting of the lift when the door is open or lock the door to block the

access to the shaft when the lift cabin is travelling; and with cabin arrestors or catchers to hold the cabin in position with a maximum load in the case of the hoist rope failure (Fig. 120), and with speed limiters, and means of egress through the roof (manhole) which should slide or open outwards.

Brackets and locking hooks are used to secure ropes and chains to the lift hooks. The length of the free end of rope spliced to ensure a

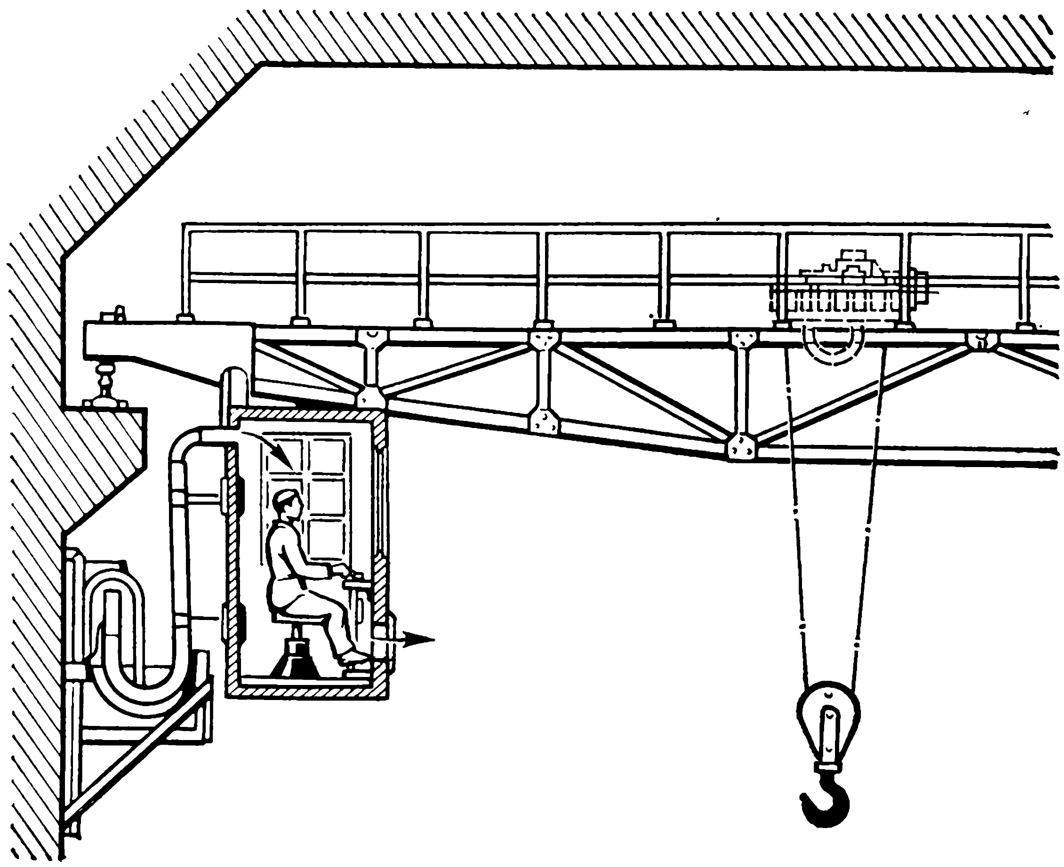

Fig. 119. Ventilation in crane operator's cabin

secure thimble or dead-eye should not be less than three times the diameter of the wire rope, but not shorter than 300 mm. Where splicing is impracticable, a good fastening can be achieved by using at least three clamps provided with bolts to secure both strands of the rope.

Cranes, hoists, lifts and pulley blocks and all the attached gear should be thoroughly inspected after erection, maintenance and periodically during service. The inspection should include testing to see if the equipment satisfies the safety requirements. The tests can be static and dynamic.

A *static test* includes lifting and holding for 10 min a test load 25% in excess of the safe operating load, and determining residual strains in the components parts of mechanisms (Fig. 121). The test load is twice the rated operating load for mechanisms intended for lifting people.

A *dynamic test* is hoisting a test load which is the rated maximum load for the given mechanism to see that all essential parts of it operate normally and safely.

After every inspection a test certificate should be drawn to certify the state of the lifting machinery, the repairs required (if any) and the maximum safe load.

Adequate clearance of not less than 400 mm should be provided between the lowest point of the crane and the highest point of the fix-

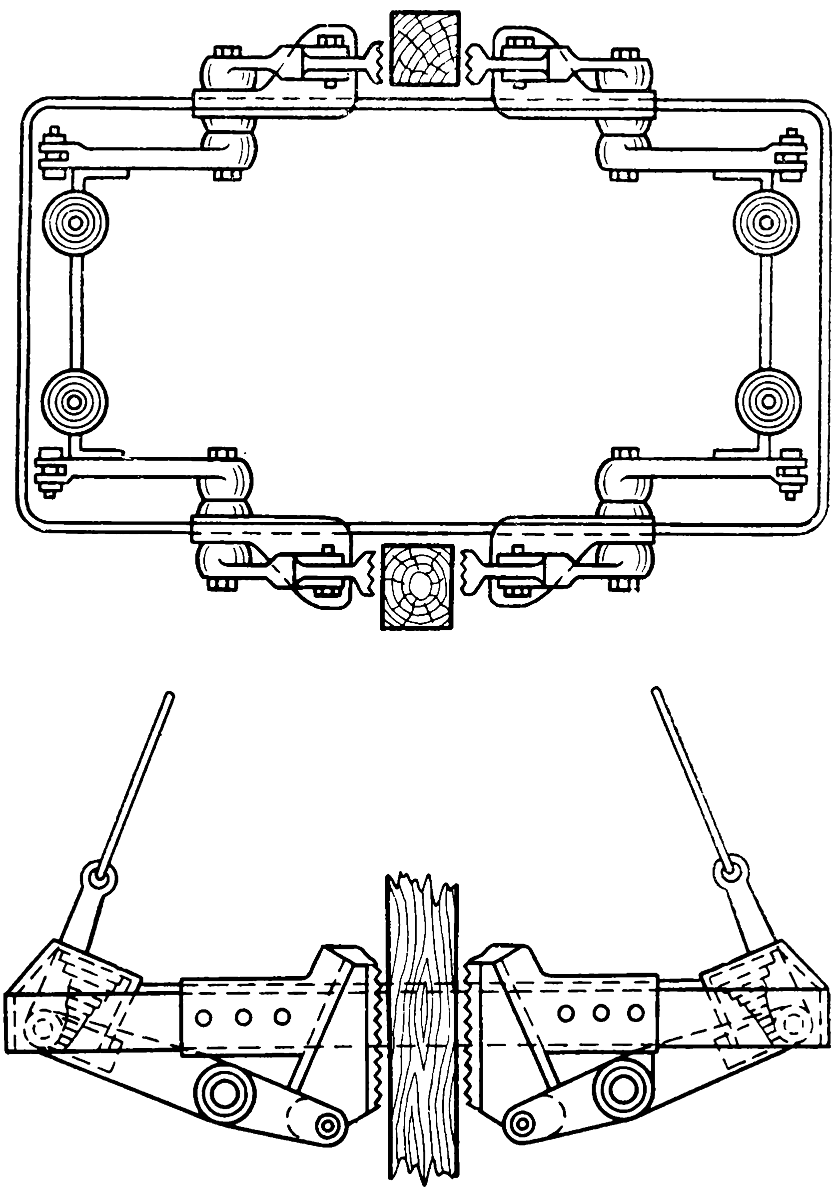

Fig. 120. A cabin arrestor

ed equipment, and about 1 800 mm between the crane highest point and the ceiling.

It is desirable that the ground-level conveyors be located near the walls. If this is impossible fly-over walkways and sideways not less than 1 m wide along the conveyors should be provided. Emergency switches should be installed at an interval of 15-20 m one from another along the length of conveyor. To ensure safe passage overhead conveyors should be guarded from below.

Traffic is limited to 5 km/h inside the production areas and to 10 km/h outside where the hard cover passages should be available. The traffic lanes inside buildings should be marked with white line and be free of fixed obstacles.

In some undertakings small-sized electric-operated cranes with a hoisting capacity up to 2 500 N can be mounted on machines or welded supports near the machines.

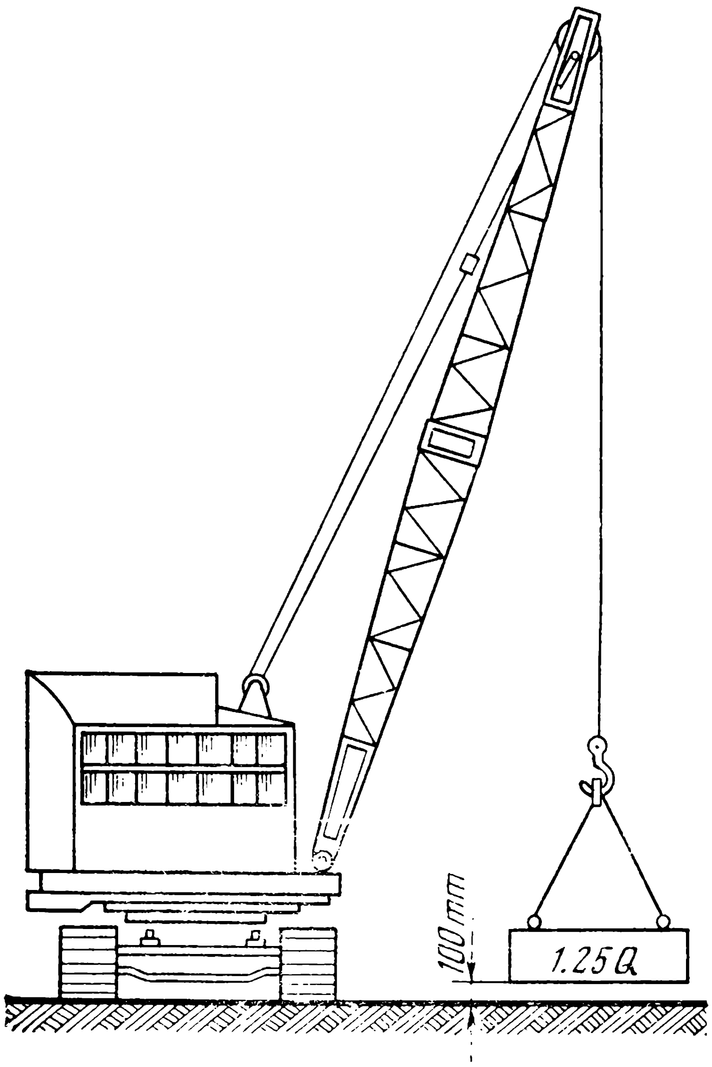

Fig. 121. A static test with a test load 25% of the safe operating load

11.9. CONDITIONS TO BE SATISFIED BY PROCESSES

We have already dealt with the general safety requirements for various processes, production areas, and open-air grounds, materials and equipment, handling, storing of finished products and raw materials, waste disposal, organization of safety work at the plant, personal protective equipment, and many other aspects of safety and hygiene.

It seems appropriate to add more and mention certain specific hazards involved in some processes, and to give the general principles of their prevention.

Gas-welding. Common hazard inherent in gas welding and cutting operations is glare which can be eliminated by enclosing the area during the operation, or carrying the operation in a fixed enclosure designed specifically for gas-welding. Goggles for welders and other workers exposed to glare have to have suitable filter lenses (Fig. 122*a*). Excessive heat, dust and gases associated with gas-welding and cutting should be removed by an effective local exhaust ventilation. Concentrations of carbon monoxide and acetylene can be diluted by general ventilation.

Acetylene generators, calcium carbide and cylinders for oxygen should be located and stored in separate places. Slaked-lime pits should be provided outside buildings.

Electric welding operations, as a rule, are performed at specialized welding stations and also wherever welding can be required around the plant for erection, maintenance and repair work. In choosing the type of electric welding for a particular job, all hazards it may invol-

ve for the personnel should be taken into account. These may include fine dust, harmful gases, high intensity radiation of visible, infra-red, ultra-violet light and X-rays, increased levels of noise and vibration. Precautions should be also taken to eliminate the risks of mechanical and electric accidents. Welding operations inside tanks and other type of closed vessels can be performed only after the work permit has been issued by the competent authority and all the necessary pre-

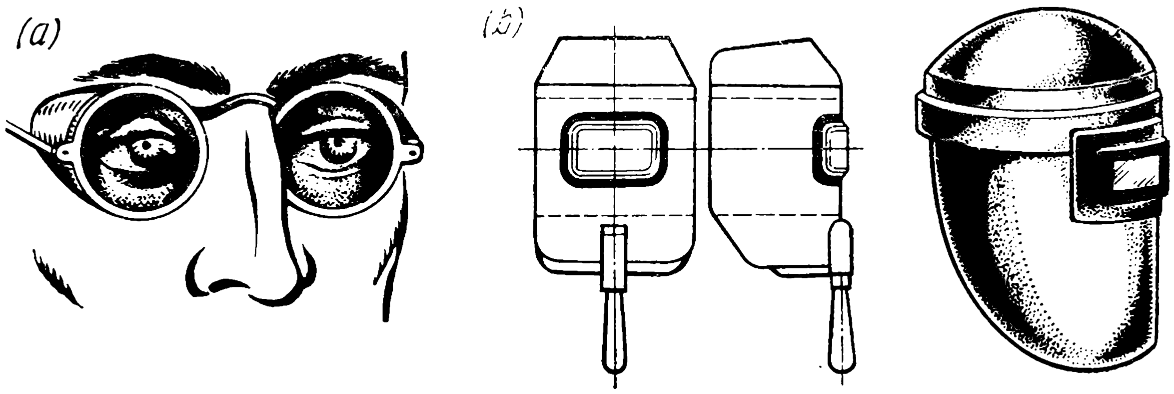

Fig. 122. Filter-lense goggles and face filter-shields for welders and other workers exposed to glare from
(*a*) gas welding; (*b*) electric-arc welding

cautions to protect the welders from possible hazards are undertaken. Where welding is part of the process it is advisable that all welding operations are carried out automatically and an effective local exhaust ventilation where necessary is provided.

At welding stations, hoisting devices should be available to assist the welder in the handling of articles heavier than 20 kg. Open welding areas should be guarded with shields made of non-flammable materials. To reduce reflection and contrast between the brightness of arc flushes and glare and that of the surroundings, the walls, ceilings, equipment should preferably be painted in grey, yellow, or light-blue colors.

All the necessary safety measures should be undertaken to ensure that the microclimatic parameters in the zone of welding stations are in accord with the standard norms established for workrooms with insignificant heat releases and intended for medium-heavy jobs.

No welding operations are allowed to be performed on pressure vessels unless they are depressurized and made safe for the work to be done, or in the rain and snow unless the workplace is in the shed.

All the necessary precautions against fire should be taken during welding operations. Thus, open-arc welding done on small and medium-sized articles should be carried out within enclosures made from fire-retardant materials. A clearance of about 50 mm should be provided between the enclosure wall lower portion and the floor. This clearance is increased to 300 mm during gas-shielded arc welding.

The area of a welding station should have a free space of not less than 3 m^2. Face shields with suitable light filters are used to protect the eyes and face of the welder (Fig. 122*b*).

Heat treatment. In the course of heat and chemical-heat treating processes a number of harmful and dangerous factors of production may influence the worker and his health. These factors are of different nature and can be classed as:

— *physical*, including travelling vehicles and mechanisms, unguarded agencies or agency parts, moved and moving parts of equipment, articles and products, high concentrations of dust in the ambient, hot surfaces and high air temperatures, increased noise levels, infra-red radiation, high relative humidity and air velocities, high voltages and electromagnetic radiation, excessive brightness of illuminated surfaces and luminaires, etc.;

— *chemical*, including noxious, irritant and carcinogenic substances; and

— *psychic* and *physiological* to which refer nervous overstress, mental and physical overload, or personal characteristic which may occasion an unsafe act.

Exhaust ventilation is a principal means of removing explosive dusts and flammable vapors from the working atmosphere. It however, requires a very careful designing and use of non-sparking types of fan. Exhaust hoods or slots should be located so that no part of the harmful fumes or dusts can enter the breathing zone. Emergency situations, often due to overheated hardening medium, excessive concentrations of hydrogen cyanide and other harmful substances, interruptions of air supply to the nozzles of gas burners in furnaces, etc., can be prevented by employing continuous processes, equipment and buildings of proper design and construction, adequate methods of storage and handling of the initial materials, finished articles, and suitable techniques of waste disposal.

Furnaces, ovens, driers and similar installations should be either gas-fired or heated electrically. The use of solid and liquid fuel can be admitted only in special, technically justified instances.

Installations located in pits (hardening tanks, quenching and pickling baths, shaft furnaces) should project to about 1 m above the ground surface; if this is impracticable, they should be fenced.

Painting. Painting and similar jobs are carried out in specialized shops and sectors by spray painting devices installed in chambers or rooms, or in floors equipped with forced ventilation (local exhaust and plenum-exhaust general ventilation) and provided with fire-fighting equipment.

Concentrations of harmful gases, vapors or fumes in the working atmosphere should not exceed the maximum safe limit values established by the appropriate safety standards and hygienic regulations. To prevent releases of harmful substances into the working atmosphe-

re the pressure in spray-painting units, rooms and chambers should be kept lower than the atmospheric pressure.

Painting operations performed on large-sized articles outside the zone covered by specialized exhaust ventilation should be authorized by the occupational health service, technical labor inspection and fire protection offices, and can be carried out only when:

— no other jobs or processes take place in the neighborhood;

— rooms are well ventilated by means of forced general ventilation;

— workers are equipped with personal means for lung protection; and

— all the necessary precautions against fire and risks of explosion are undertaken.

Woodworking. Prior to being dressed and cut, logs and lumber should be checked for tramp iron with metal detectors and tramp iron catchers. Appropriate haulage devices should be provided, and the workers bucking logs should clear their workplaces of all obstructions before starting work. Cross-cutting saws for round timber billets poles and the like should have a feeding appliance such as a rocking frame or a roll table provided with spikes or other devices that securely hold the wood in position. Chips, splinters and the like should be not removed by hand from the blade or workbench while the saw is in motion. The floor or ground used by the workers for operating circular saws should not be obstructed, but afford workers a firm footing and have passages not less than 1 m wide. The wooden waste should be removed and disposed mechanically. Pneumatic devices can be effectively used for sawdust, shavings and dust with a moisture content below 20%. Adequate measures should be taken to prevent self-ignition of wood waste at disposal areas.

Metal plating. Despite the diversity of metal plating techniques (electroplating, chemical-conversion coating, anodic coating, hot-dip metal coating, and metal spraying) the process should satisfy the general requirements which are common for all the stages of the process, i.e. surface cleaning, preparation of electrolyte solutions, plating and finishing. As far as practicable process operations and procedures involving many hazards and risky factors should be automated and carried out in environmentally-controlled rooms or enclosures. Hand labor should be replaced with power-driven and automatically controlled machines and mechanisms. It is also desirable where practicable to substitute inert and non-flammable process materials for toxic and flammable substances.

Shot-blast and sand-water cleaning methods are widely used for the surface treatment of articles. Dry quartz sand however should not be used for shot-blasting. The starting devices in shot-blasting and sand-water cleaning chambers must be interlocked with the charging gates. The gates in hydrocleaning chambers should be interlocked with high-pressure pumps.

When mixing acids for process solutions care should be taken when mixing acids with water. Acids must be added in the order of their increasing densities. Water-acid solutions are prepared by pouring a thin stream of acid to cold water which is continuously agitated to eliminate rapid heating and splashing. Foul (spent) electrolyte should be neutralized before it goes down the waste pit.

Handling of chemical substances requires special safety precautions. Glass vessels for liquid acids and alkalis are as a rule handled in specialized carts or vehicles by two persons at a speed of not more than 5 km/h; liquid fuel and inflammable substances are usually piped to the places where they are required for the process in large quantities. With the requirements less than 200 kg per shift, such substances are supplied to the workplaces in closed shock-proof containers or crates by loaders or other mechanical means of handling loads.

Handling and loading operations may be performed by the workers manually and with the help of specialized mechanisms and machines such as winches, blocks, jacks, roller tables, elevators, loaders, cranes and conveyors. Before suitable precautions against accidents can be taken it is necessary to know exactly how and why they occur. Usually in jobs involving handling and loading accidents may be due to unsafe mechanical or physical condition (improperly guarded parts of machines, hazardous arrangement, improper illumination, ventilation, clothes and poor housekeeping). Where reasonable and practicable, mechanical appliances should be provided and used for lifting and carrying loads. Workers assigned to handling loads should be instructed how to lift and carry safely. No person should be employed to lift, carry or move any load so heavy as to be likely to cause injury to him.

Frequent lifting by hand and carrying loads over long distances may cause rapid fatigue and overstress in the body. Dangerous situations during loading operations may arise due to obstructions, improper illumination, misplacement of tools and materials around the place. When pulley blocks are used cases are not infrequent when the rope becomes caught between the sheave and the side of block, or fits improperly on the sheave and causes distortion, and fall of the load. Hoisting drums should be provided with a flange on each side large enough to prevent the rope slipping off the drum. The following lifting tackle should not be used:

— wire ropes when their strength is affected by broken wires, wear or corrosion;

— fibre ropes when they show substantial deterioration;

— chains, rings, hooks, shackles and swivels if they show signs of stretch, wear, cracks or open welds.

Chutes are often used for handling loads in storehouses. It is essential that a suitable angle of the chute inclination is chosen to prevent slippage and falls of loads which may cause serious injuries.

Crane operators working in the so-called hot-work departments are often exposed to excessive radiant heat and noxious gases. It is therefore essential to make sure that the operator's cabin is well ventilated, lit and comfortable to ensure normal working conditions for the person during working hours.

Fixed hoisting and handling equipment should be installed so that it cannot be displaced by the load, vibration or other influences; the operator is not exposed to danger from loads, ropes or drums; the

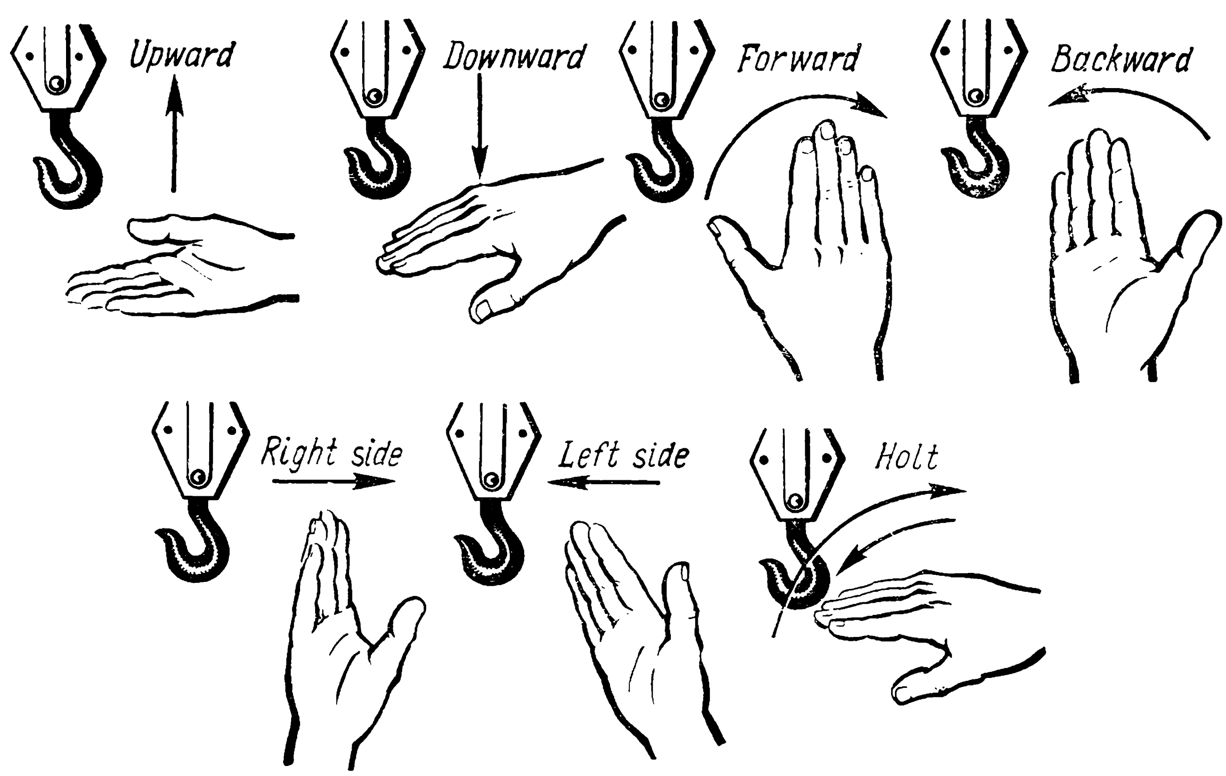

Fig. 123. A code of sign signals used in material and freight handling

operator can either see over the zone of operation or communicate with other persons at all loading and unloading points by the adopted sign signals or other adequate means (Fig. 123).

Adequate clearance should be provided between vehicles, moving parts and loads of hoisting equipment and fixed objects such as walls and posts, and electrical conductors.

In hydraulic lifting machinery only approved materials should be used in the construction or repair of hydraulic systems, and the safe working loads of the machine should be clearly indicated. Hydraulic lifting machinery should be equipped with flow-regulating safety devices to prevent uncontrolled operations through:

— accidental contact with the operating controls, or

— failure of the pressure supply system.

Appropriate relief-valves should be included in all systems to prevent overloading of the machine or failure of the equipment that can cause injury to the operator.

Electrically driven hoisting and handling equipment should be installed so that:

— the starting device should return to the "off" position when released;

— when auxiliary current is supplied a short circuit in the auxiliary current system cannot lead to the motor starting or continuing to run, or the brake being released or remaining released.

The controls of hoisting and handling equipment should be so situated that the driver at his stand or seat has ample room for operation and an unrestricted view, and remains clear of the load and ropes, and that no load passes over him, and should be provided where necessary with a suitable locking device to prevent accidental movement or displacement.

Control handles should move in the direction of the resultant load movement. Pedals should have a non-slip surface.

Hoisting and transport equipment should be equipped with brakes capable of effectively arresting and holding a load at least 1.5 times the safe working load. A locking device should be provided, if necessary.

The brakes should act without shock and delay and be provided with easily accessible means of adjustment.

Hoisting and handling equipment should be operated only by persons instructed and trained in its use. Adequate precautions should be taken to prevent such equipment from being set in motion by unauthorized persons. Hoisting and transport equipment should be used only for the purposes for which it is suitable. Loads should be securely attached. No load should be moved on a hoisting mechanism unless the agreed signal has been given and accepted by the operator. The signalling code should be posted up conspicuously at suitable places. Loads should be raised and lowered smoothly, avoiding sudden jerks. Loads should not pass or remain suspended over persons. No person should pass or stand under a suspended load. The operator should not leave the equipment unattended with power on or with a load suspended.

CHAPTER 12

Sanitation and Hygiene Requirements for Industrial Establishments

Industrial establishments should be designed and constructed so as to satisfy the basic conditions of industrial hygiene and sanitation of which the prevention of air pollution and contamination of the environment are most important. Stringent hygienic requirements for industrial establishments can be met by proper planning of industrial layouts, use of equipment, machines and processes which

give no or minimum harmful and odorous substances into the working ambient, the atmosphere and the sewage;

no or minimum excess heat and moisture at the workplaces;

produce no or minimum noise (and ultrasound), vibration, electromagnetic r.f. waves, static electricity, and ionizing radiations.

Among other measures to be taken to improve occupational hygiene and safety at plants are the replacement of processes involving health hazards (noise, vibrations, etc.) by those in which these hazards are eliminated or minimized, i.e. substituting electric heating for plasma heating, gas fuel for solid and liquid fuels, resorting to extensive mechanization, automation and use of distant control systems.

Proper choice of the site for plants relative to living quarters and a suitable placing of the production departments and shops on the site with respect to one another and the flow-sheet are also very important.

12.1. SANITARY SAFEGUARD AREAS

All the industrial establishments which are sources or include sources of health hazards should be located at a distance from the housing areas. This distance, called the sanitary safeguard, also protection zone or area, may vary from 1 000 to 500 m, and is assigned according to the character of the process and the production capacity by which all industrial establishments may be divided into five classes. The first three classes (I, II and III) include metallurgical, chemical and petrochemical industrial plants and have the sanitary safeguards of 1 000, 500 and 300 m, respectively. All plants involved

in mechanical engineering are under the Classes IV and V in which the sanitary safeguard zones are 100 and 50 m, respectively.

Class IV includes electrotechnical plants having foundries and similar "hot-work" processes, and metal-working undertakings with iron and steel foundries (with an output up to 10 000 tons per year), and non-ferrous metal casting processes (with an output up to 100 tons per year), etc.

Class V includes metal-working plants with heat-treating processes (without foundry practice), electrotechnical undertakings (without foundry or mercury processes), etc.

Such protective distances are necessary to minimize the intensities of noise and reduce the carryover of harmful gases, fumes and dusts beyond the zone to the neighboring housing areas. The sanitary safeguard areas if necessary can be increased but not more than three-fold.

Such zones cannot be regarded as redundant areas and used for the expansion of production facilities. However, the zones can be used for the construction of premises for the management, service facilities, storage houses, garages and engine-rooms, parking-lots, trade and catering facilities, etc. The plants which are safe and in accord with the safety requirements for housing areas and do not need railway approaches, may be located within residential districts.

12.2. SITING OF BUILDINGS

If a new factory is to be built or an existing one reconstructed there are many things affecting both safety and production that should be taken into account. It is essential that safety and hygiene considerations based on the hygienic regulations established in national or other recognized standards and applicable to the type of establishment be borne in mind at the time of planning.

Proper choice of the site for a new establishment should take into account the climatic and terrain features of the locality, intensity of sun radiation, the direction of winds, the conditions of fog generation and the flue-gas dispersion in the atmosphere, under the local conditions.

As far as practicable the site should be level, accessible for traffic and people, and gently sloping for an effective surface run-off. Proper drainage should be provided to divert the rain and snow-melt waters and prevent rise of the ground water. To avoid serious accidents from waterlogging, the water table should be maintained below the basements of the subsurface structures, such as cableway trenches, pipelines and other important service lines.

An adequate sanitary zone should separate the plant with harmful releases (smoke, fumes, gases, dust and odorous substances) from the

neighboring housing areas located on the windward side of it relative to the prevailing winds of the locality.

Buildings and structures should be suitably placed over the site so as to make good use of the conditions for natural lighting and ventilation, and for the protection against insolation.

Normally, industrial buildings and structures are situated so as to suit best the process (flow-sheet) and are grouped according to the common requirements for power, distribution of the personnel and traffic (to avoid overcrowding), and hygiene and fire-protection.

The space between buildings illuminated naturally through window openings should be not less than the cornice height of the tallest of the two opposing buildings.

In all cases where the terrain features, hygiene and fire-protection requirements permit, it is feasible to situate as many workshops (departments) as possible in one building, but so as not to hamper or interrupt the process. Where several shops are housed in one building, those with similar hygienic conditions should be groupped into sectors isolated from one another.

In laying out a machine-building plant it is desirable to group its workshops according to the following zones:

— *hot-process zone*, includes foundries, forge shops, press and die-forging and heat-treating shops characterized by excessive releases of dust, smoke and other harmful substances, also by noise and serious fire risks;

— *cold-process zone*, comprises machine shops, assembly and finishing departments, sheet-metal press working shops and similar work areas. Because these shops employ the largest part of manpower of the plant, this zone should preferably be situated closer to the main gates and have suitable access to the hot-process zone from which castings, blanks and workpieces are delivered;

— *woodworking zone*, includes sawframes, woodworking shops, pattern departments, box and crate shops, driers, and timber stock yard. Because of special fire risks, this zone should be located at a safe distance from the hot-process zone;

— *steam and gas generation zone*, includes boiler plants and gas generating installations which, due to much smoke, gas and dust they give off into the air, should be situated as far as practicable from the principal departments, main gates, management buildings, with due regard to the prevailing winds in the locality;

— *service-shop zone*, comprises tool-making, mechanical repair, electric maintenance shops, etc.

There is a number of principles the designer can generally follow in planning for a safe and efficient production. To facilitate natural ventilation and increase air changes it is advisable to locate the shops with excess gas, smoke and dust releases along the longest outside wall of the building. If such layout inside the building is impossible,

adequate air changes should be effected through forced ventilation. Aeration (natural ventilation) of workrooms can prevent accumulation of excessive heat, gases and dust conducive to accidents. It is sometimes desirable that "hot-work" departments be located in single-storeyed buildings oriented perpendicular, or at 45°, to the prevailing winds.

The group of processes with noise intensities above 85 db, and those accompanied by the contamination of the working atmosphere should be placed in separate workrooms properly isolated from other workplaces.

Basements or socle floors should not be used as production areas except for the cases when this is necessary for technological reasons.

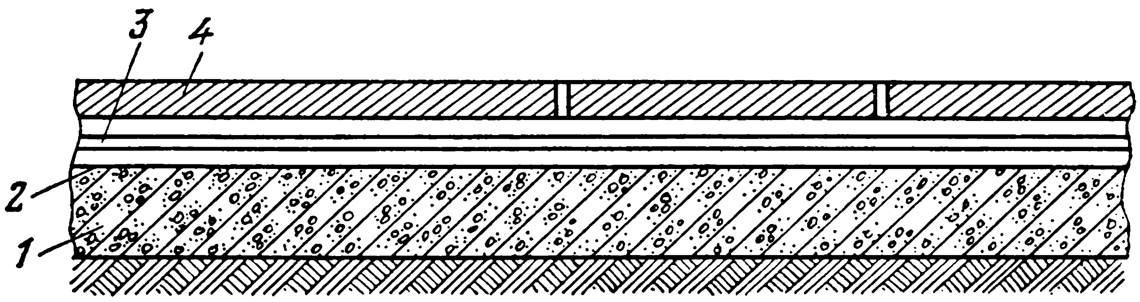

Fig. 124. An acid-resistant floor
1 — concrete subgrade; *2* — roofing paper; *3* — acid-proof mastic; *4* — ceramic tiles

The structural elements for industrial-type buildings should satisfy the following conditions:

— outside walls in heated buildings should be made so as to prevent condensation of moisture on the internal surfaces. The choice of building materials for the inside walls, partitions, floors, etc., should proceed from the anticipated relative air humidity within the work enclosure;

— the floors in industrial buildings should be sufficiently firm, continuous and even to permit safe walking, easy cleaning and, if necessary, safe handling of materials. The floors should not be slippery and, if necessary should be roughened or provided with non-slip surfaces. The heat reception (absorption) coefficient of floor materials in heated rooms which are permanently occupied should not be more than 5.8 kW/(m K). It is therefore recommended to use: wood for the floors in machine-shops, tool-making departments, cloak-rooms and office-rooms; asphalt or cement-concrete for the floors in wet working enclosures; clinker, concrete and ceramic tiles in heat-treating shops, toilets and washing facilities; and acid-resisting asphalt concrete and ceramic tiles in workrooms in which the floors are likely to be affected by acids (Fig. 124).

Adequate roads and sidewalks asphalted, and well illuminated should be provided in the factory yard. Cross-roads, pedestrian lines and crossings should be laid at right angles, and where possible, at different levels.

12.3. WATER SUPPLY AND SEWAGE

In industrial and ancillary buildings an adequate supply of water for process and drinking purposes is provided by internal pipe-line systems. All water furnished for the drinking purpose should be from the public water pipe-line or from a source (sources) approved by the competent health authority and controlled for quality in the manner prescribed by this authority.

Sewage system, i.e. pipes and ducts should be provided to convey the industrial waste from plants to a place of disposal. All the plants should have sewage treatment facilities, such as sedimentation or settling tanks and vats for clarifying service waters containing suspended and floating substances; and water-purification plants for the chemical cleaning of process waters. The degree of water pollution varies and depends on the use made of it in the industry. Ventilation openings should be provided in sewage pits and ducts to prevent the danger of losing consciousness through asphyxia or of poisoning by harmful gases (hydrogen sulfide, methane, hydrogen, etc.) during maintenance, cleaning and repair work. No open flames or smoking should be permitted in or near open lime pits and sewage shafts. The premises housing sedimentation tanks and the like structures should be properly ventilated. There should be no direct communication between sewage cellars and ducts and the production areas except through a sufficiently deep hydraulic lock.

12.4. HYGIENE AND SERVICE FACILITIES

General provisions. Toilet and washing facilities, cloakrooms and other personal service rooms should be as far as practical:

— be suitably situated, dimensioned, constructed, enclosed and equipped for their purposes;

— have floors, walls and ceilings that are easy to clean;

— be maintained in a clean and sanitary condition, and protected against dangerous or harmful effects of processes;

— be well ventilated, lighted and if necessary heated.

Wastes from such facilities should be properly disposed of.

Toilets. As far as practicable workers should be provided with toilet facilities separate for each sex. For personal cleansing, an adequate supply of toilet paper, or where conditions require, water, soap and towels should be provided at, or in rooms adjacent to the toilet

facilities, which should conform to the requirements of the competent health authority.

Washing facilities. As far as practicable, suitable and sufficient facilities for washing should be provided for the workers, and should comprise:

— a sufficient flow of clean water;

— a sufficient quantity of soap and towels for personal use.

As far as practicable and in particular where workers are exposed to skin contamination by poisonous, infectious or irritating substances, showers should be provided.

Cloakrooms. As a rule all workers regularly employed should be provided with cloakroom facilities and personal lockers situated near the washing facilities and equipped for the storage of their working and personal clothing. Cloakrooms should not be used for any other purpose. Where necessary to prevent danger, suitable arrangements should be made for disinfecting cloakrooms in conformity with the requirements of the competent health authority.

Medical aid. Except emergencies, first aid in the case of accident or sudden illness should be provided only by a medical practitioner, a registered nurse or a person trained in first aid and possessing a first-aid certificate acceptable to the competent health authority. As far as practicable, adequate means and trained personnel for rendering first aid should be readily available during working hours at places where work is carried out. All injuries, however slight, should be reported to the nearest first-aid man or room and treated as soon as practicable.

First-aid boxes should be provided at suitable places near workplaces, on vehicles, machines and installations and be protected against contamination by dust, moisture, etc. First-aid boxes should contain adequate materials for rendering first aid to workers. The content of first-aid boxes should comply with the relevant provisions of national health regulations and standards. First-aid boxes should be clearly marked with the words "First Aid" or by a conventional symbol, and contain simple and clear instructions to be followed in emergency cases. The content and the condition of every first-aid box should be inspected at regular intervals by the person in charge of it.

A suitably equipped first-aid room or rooms should be provided at a readily accessible place or places for the treatment of minor injuries and as a rest place for seriously sick or injured workers. The first-aid room should be under the supervision of a doctor.

Notices should be conspicuously exhibited at suitable places stating:

— the position of the nearest first-aid box, room, and the place where the person in charge can be found;

— the position of the nearest telephone for calling the ambulance.

Steps should be taken to teach first aid to a reasonable number of workers. The first-aid personnel should be adequately trained in resuscitation procedures and resuscitation apparatus. The latter should be used only by persons trained in its use.

A first-aid register accessible only to authorized persons should be kept at each first-aid room for recording the names of victims, particulars of injuries and treatment.

INDEX

TO THE READER

Mir Publishers welcome your comments on the content, translation, and design of the book.

We would also be pleased to receive any suggestions you care to make about our future publications.

Our address is:

USSR, 129820, Moscow I-110, GSP, Pervy Rizhsky Pereulok, 2, Mir Publishers

Printed in the Union of Soviet Socialist Republics

ALSO FROM MIR PUBLISHERS...

Vladimirov, V. MEASURING AND CUTTING TOOLS. MANUFACTURE AND REPAIR

A textbook on measuring and gauging equipment and on cutting tools most widely used in tool making. Intended for individual and group training of toolmen, may also be useful for technical schools and colleges, apprentice engineers and inspection personnel at engineering and instrument- and tool-making plants.

The book provides information on tool manufacturing, presents a complete description of tools and instruments presently in use, considers in detail their design, methods of maintenance and repair along with the data on their accuracy, reliability, adjustment and verification techniques.

Set forth in the book are also data on materials used in manufacture of cutting tools, and on features of their heat and chemical treatment. Describes applications of diamonds and diamond cutting tools, hard and extrahard synthetic materials.